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Acoustics Research in Europe and the Soviet Union

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This issue of European Science Notes Information Bulletin presents the view of European acoustics research developed by Dr. David Feit while serving as Liaison Scientist at the Office of Naval Research European Office (ONREUR) for the past 2 years. Dr. Feit is an internationally recognized expert in the field of structural acoustics and mechanics, and the coauthor with Miguel Junger of *Sound, Structures and their Interaction*. While at ONREUR, Dr. Feit has followed developments in structural acoustics, underwater acoustics, and physical acoustics. Activity in these specialties in Europe ranges from architectural applications, to active noise cancellation in automobiles and aircraft, to the areas of traditional naval interest in underwater sound propagation and signal processing. Working with other members of the ONREUR professional staff, Dr. Feit here presents a current perspective on the field. As in all ONREUR reporting, there is no claim to global coverage of the field--rather it is the appraisal drawn from selected professional visits during the past 2 years.

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This publication is approved for official dissemination of technical and scientific information of interest to the Defense research community and the scientific community at large.

Commanding Officer ...... CAPT Victor L. Pesce, USN
Scientific Director .... James E. Andrews
Editor .... Ms. Connie R. Orendorf

An Issue Focused on Acoustics Research in Europe and the Soviet Union

by Dr. James E. Andrews, ONREUR Scientific Director

This issue of European Science Notes Information Bulletin presents the view of European acoustics research developed by Dr. David Feit while serving as Liaison Scientist at the Office of Naval Research European Office (ONREUR) for the past 2 years. Dr. Feit is an internationally recognized expert in the field of structural acoustics and mechanics, and the coauthor with Miguel Junger of *Sound, Structures and their Interaction*. While at ONREUR, Dr. Feit has followed developments in structural acoustics, underwater acoustics, and physical acoustics. Activity in these specialties in Europe ranges from architectural applications, to active noise cancellation in automobiles and aircraft, to the areas of traditional naval interest in underwater sound propagation and signal processing. Working with other members of the ONREUR professional staff, Dr. Feit here presents a current perspective on the field. As in all ONREUR reporting, there is no claim to global coverage of the field--rather it is the appraisal drawn from selected professional visits during the past 2 years.

It is interesting to note that interest in the broad range of acoustic studies is growing, and that environmental acoustics and ocean acoustics are receiving renewed attention from investigators in a variety of other scientific disciplines. Recently the SACLANT Undersea Research Center hosted a workshop designed to bring together geophysicists and acousticians to approach a common understanding of the ocean floor and its effect on, or analysis by means of, acoustic energy in the ocean. The Intergovernmental Oceanographic Commission (IOC) of UNESCO is proposing to create its first expert working group in ocean acoustics following a successful conference on that topic in Beijing last March.

Also summarized in this issue is the Heard Island Experiment organized by Professor Walter Munk of Scripps Institution of Oceanography, San Diego, California. This was the topic of the Office of Naval Research inaugural International Science Lecture Series. The Heard Island Experiment is drawing wide attention and international participation in its undertaking to validate the application of ocean acoustic tomography to the monitoring of global climate temperature changes.

Thanks go to Dr. Feit from ONREUR for his dedicated and highly professional contributions to the development of broader scientific understanding and international contacts during his tenure.

Acoustics Research in Europe--A Personal Assessment

by David Feit, the Liaison Scientist for Acoustics and Mechanics in Europe and the Middle East for the Office of Naval Research European Office. Dr. Feit is on leave from the David Taylor Research Center, Bethesda, Maryland, where he is a research scientist in the Ship Acoustics Department.

Introduction

Acoustics, the science of sound, encompasses the study of the generation, transmission, and reception of wave-like disturbances as they travel through a variety of media. These can include air-airborne acoustics, water-underwater acoustics, solid elastic media-elastic wave propagation, and systems of interacting fluids and structures which some of us in the U.S. now address as the area of structural acoustics.

This assessment of the state of acoustics research in Europe is based on impressions gained through a series of liaison visits and conference attendance since coming to the Office of Naval Research European Office (ONREUR) in January 1988. In my visits, I indicate to my hosts that not only am I interested in acoustics *per se,* but also in the general areas of solid and fluid mechanics.

Countries Visited

During the first half of my tour, I visited (in alphabetical order) Belgium, Denmark, Federal Republic of Germany (FRG), France, Ireland, Israel, the Netherlands, Spain, and the U.K. During the latter half of my assignment, tremendous political changes took place throughout the world; these changes radically altered my plans. Because of the increased accessibility (*glasnost*) and democratization of the Central European countries (formerly referred to as Eastern Bloc countries), I sought opportunities to make liaison visits to countries that were previously closed to ONREUR scientists. With this in mind, I visited Bulgaria, the U.S.S.R., and Yugoslavia. Although I was not there on business and cannot assess the state of acoustics or mechanics research there, I also recently visited Czechoslovakia on a family holiday. I can attest to the friendliness and enthusiasm of the people as well as the beauty and charm of its capital, Prague. Based on these visits, my reports are included separately since the trips to the U.S.S.R. and Bulgaria came at the end of my tour and require a bit more gestation and background information before I write them.

Unfortunately, although I had planned a visit to Norway and Sweden, this was canceled because of budgetary constraints. The lack of information on their activities should in no way be interpreted as a lack of interest on my part or an indication of their capabilities or efforts in the field of acoustics. I include Denmark, very strong in acoustics research, in my discussion.

Leading Research Activities

From my perspective, the strongest research activities are centered in the U.K., France, and FRG. As in the U.S., a strong motivating factor for acoustics research of the respective countries is the naval activities and underwater acoustics requirements. Accordingly, in the general area of underwater acoustics research, I rank the efforts in the above order.

On the other hand, in Europe there is a keen interest in the quality of life and strong public pressure to protect the environment. Because of the "green movement," the public is very much aware of acoustics and its effects on the community. This motivating factor has a strong influence on public policy and its concomitant effect on the number of government-sponsored studies related to the environmental impact and control of airborne acoustics. In this area, I reverse the ranking of the above three countries with respect to the quality and strength of their research activities. I will emphasize these comments in more detail later.

There are of course first-rate research efforts being pursued in the other countries surveyed, but at a much lower level of effort than in these three countries. I do not have hard figures to document this. My impressions are based on conversations and interviews with a few academic and industrially based researchers. A more objective assessment must include such factors as the per capita expenditures on research in the specific area of interest.

Acoustics Research in Denmark

As an example of the difficulties inherent in making such comparative judgement, let us investigate Denmark. Like several other countries I visited, I did not include it in my list of major contributors to acoustics research. Although Denmark has a relatively small population, it is the home base of B&K Instruments, probably the world's leading developer and supplier of acoustical instrumentation. To maintain this position, it supports its own research and development (R&D), and most likely for competitive purposes awaits the introduction of a product line before revealing the full extent and scope of its research directions. In addition, there is a world-class acoustics research group at the Technical University of Denmark directed by Professor Leif Bjørno, that adds considerably to the calibre of the Danish research activities.

Although I will concentrate my evaluative comments on the three major countries mentioned above in the acoustical arena, I do not mean to imply that efforts in the other countries are less worthy. They are only perhaps a bit less extensive.

Acoustics Research in the U.K.

Modern acoustics was born in the U.K. as a result of the fundamental work on acoustics, "The Theory of Sound," by Lord Rayleigh in the late 19th century. The first volume on acoustics *per se* and the second on the theory of vibrations, have been the basic references for almost all the work in acoustics up to the present.

Although now retired as the provost of University College, London, Sir James Lighthill continues to do research in fluid mechanics and wave propagation as a member of the mathematics department. Recently, he was introduced at a Cambridge University seminar as the "greatest fluid dynamicist and applied mathematician of the century." In the past, he was instrumental in the training and subsequent careers of some of the U.K. leaders in acoustics research. These leaders include Professors J.E. Ffowcs-Williams and D.G. Crighton, Cambridge University, and Dr. M.A. Swinbanks, an independent consultant living in Cambridge. Swinbanks has pioneered in active control applied to acoustics and vibrations. These individuals, together with Dr. Ann Dowling, a former student of Ffowcs-Williams and now a lecturer at Cambridge, help to maintain Cambridge University as a center of excellence in acoustics research. In 1990, Dr. Dowling won the A.B. Wood Medal presented by British Institute of Acoustics.

Sir James has not only been a principal driver in acoustics efforts, but I would say the field of mechanics in general. He recently stepped down as President of the International Union of Applied Mechanics. Before doing so he contributed to the organization several symposia on ship dynamics (see this issue, page 30, "Royal Society Discusses the Dynamics of Ships"). His own latest research endeavors are in the fluid mechanics of fish locomotion (ESNIB 89-10).

Institute of Sound and Vibration, Southampton University. In addition to Cambridge University, another world-renowned center in acoustics exists at the Institute of Sound and Vibration Research (ISVR) of Southampton University. In 1990, Professor C.G. Rice became ISVR's director, succeeding Professor R.G. White. Professor White returns to his position as Professor of Vibration Studies after a very successful term as director. J.K. Hammond, well known for his work in acoustic signal processing, has been named deputy director.

There are radical changes in university and research funding taking place in the U.K. There will be more reliance on external funding as opposed to the munificent government grants of the past. Professor Hammond will coordinate research, which effectively means an institute-wide review of the research activities and prioritizing the future research activities.

A notable achievement for ISVR is their top 5-point rating in the University Funding Council research selectivity exercise. This ranking is equivalent to "research quality that equates to attainable levels of international excellence in some subject areas of activity and to attainable levels of national excellence in virtually all others." Furthermore, this institution has recently completed a unique water tank dedicated to underwater acoustics research that rivals and surpasses many currently available facilities in the U.S.

In addition, there is a large effort in active noise and vibration control under the direction of Drs. P. Elliot and S. Nelson. Active control uses the principle of superimposing an out-of-phase signal with the unwanted signal to produce a null or substantially reduced field at desired locations. One particular effort, the development of a system to reduce the interior cabin noise levels of an in-flight British Aerospace Corporation airplane, has been publicized recently in both the public press and scientific journals (ESNIB 89-10:2-4).

In spring 1989, ISVR provided a short course dedicated to "Active Control of Sound and Vibration." This course was jointly sponsored with Lotus Engineering, a division of Lotus Cars. One of the practical applications discussed at this course was a system developed by Lotus Engineering to control the interior noise induced by automobile engines. An automobile fitted with the system was available during the course so that we could experience its effectiveness. The system uses eight ear-level sensors, four in the front and four in the rear, that send their information to an adaptive noise control computer which in turn drives the six speakers of the car's "entertainment system." The computer also receives an engine tachometer signal. The system reduces the low-frequency "boom" (100 to 200 Hz) associated with engine rpm. Other practical applications discussed were related to helicopter vibration problems, vehicle suspension systems, reduction of background noise in pilot headsets, and control of duct-borne noise in a gas turbine pumping station. I came away with the impression that using active control in practical engineering systems is very vigorously pursued in the U.K. at academic and industrial levels.

These efforts, as well as others, taking place (e.g., at Topexpress Ltd., Cambridge) apparently are well ahead of any similar efforts in the U.S. in terms of civil applications. I have avoided contact with the military applications aspects of this technology. However, be aware that in the U.S. I have only been a bystander to this field of application. Conversely, in my current position I am specifically looking for technology developments as part of my assignment.

There are apparent signs of a high degree of competitiveness in this area. On the one hand, this is healthy because it spurs on progress. At the same time, there are signs of hard feelings between major players. Within the last year, I have heard that Topexpress has scaled down its efforts in this area, and several active individuals have left Topexpress to form their own company. Drs. C. Ross, A. Langley, and G. Eatwell have formed 2020 Science, Ltd, also located in Cambridge. This company is now part of Noise Control Technology, Inc., Linthicum, Maryland.

There are several other institutions in the U.K. where research relevant to acoustics and vibrations take place. These include an excellent, but relatively unknown, group dedicated to maritime engineering at Brunel University (Professor Price, director) and a dedicated under- and post-graduate acoustics program at the University of Salford. Professor Price has recently taken up the position of Professor of Ship Science at Southampton University (see this issue, page 26, "Symposium on the Dynamics of Marine Vehicles and Structures in Waves").

At the Open University in Milton Keynes, U.K., Professor K. Attenborough, directs an excellent effort in the propagation of airborne sound over noise barriers and ground surfaces. This work is particularly relevant to the issue of the environmental impact of sound caused by transportation systems. In addition, Professor Berktay directs work in underwater acoustics at the University of Bath.

The British Institute of Acoustics holds two national meetings each year as well as several specialist-type meetings. The national meetings attract an audience of about 150-200 which on a per capita basis is very comparable to the attendance figures of the Acoustical Society of America (see this issue, page 7, "The British Institute of Acoustics").

In the U.K., several industrial firms doing both classified and unclassified work relevant to the acoustic quieting of naval vessels. Without discussing the particulars, I would judge this work to be on a par with that in the U.S., but at a proportionately lower level of effort. I visited Topexpress, Ltd.; Plessey Naval Systems, Templecombe; YARD, Ltd., Glasgow, Scotland; and GEC Marconi Research Center. All of these companies have contacted U.S. research sponsors and made proposals to address specific areas of research in which they are most competent.

Samples of their work were presented at Undersea Defense Technology (UDT) meetings held in November, 1988 (see ESNIB 89-08) and February 1990. In 1991, UDT will meet in Paris. These UDT meetings provide an excellent forum in which to learn quickly who are the major players in European underwater acoustics technology development. I was very glad to see a large contingent of U.S. Navy laboratory representatives at the most recent UDT meeting.

Acoustics Research in France

About 15 years ago, M.C. Junger did a survey for Office of Naval Research London (ONRL) of acoustic research efforts in France, reported in an ONRL Memorandum entitled "Sonar and Ship Silencing Research and Development in France," dated December 31, 1975. Reading between the lines, one could surmise that the calibre and quantity of acoustics research in France at that time was not high. Since then, however, France has made rapid strides in the amount and quality of acoustics-related research.

These efforts have been, I believe, spurred on very strongly by their naval requirements. In recent years, they have been working on the design of a new class of nuclear-propelled submarine. This program is well publicized and until very recently, the design was being promoted for sale to Canada for their nuclear submarine construction program (I understand that now the Canadian submarine construction program has been curtailed).

In the intervening years since the Junger report, the acoustics program at the Technical University of Compiégne is more modern and extensive. Interestingly enough, Junger spent a semester at Compiégne and coauthored a book with Professor M. Pierulli (in French) on acoustics and vibrations. Professor Pierulli is now on the faculty at the University of Paris VII. Professor de Bellaval chairs the vibrations and acoustics group. His research interests are in the area of nondestructive evaluation using ultrasonics. During my last visit there in June 1990, I learned that a National Center for Scientific Research (CNRS) laboratory dedicated to acoustics and vibrations has been created at Compiégne. This can be viewed as recognition by the centrally directed research authority of the excellence of the Compiégne program. This group consists of eight faculty members and six graduate engineers. Together with both graduate and undergraduate students, there are about 50 investigators at the center.

I visited with Professor P. Wagstaff, a U.K. citizen who has been with Compiégne for the last 10 years. He has done some excellent research in source localization in reverberant environments, and is a principal consultant to several French naval laboratories. Several of his students are now working in responsible positions in these laboratories. Recently, he organized a company called Acovib. This company will be housed in a university complex created specifically to accommodate small research firms that are spinoffs from university activities. This is an example of the close relationship between academia and private industry that the University of Compiégne tries to encourage. M. Hamdi, another professor in the group, has published extensively in computational acoustics and has also formed a company called Statcom. This company sells computer program packages, including graphic routines, for acoustic radiation and scattering by elastic structures with various degrees of internal complexity. This program has capabilities comparable to some inhouse generated programs at U.S. naval laboratories. The French effort is being supported not only by the French Navy, but also by the European Space Agency and European automobile manufacturers.

Relative to this, I find it very interesting that computational approaches to structural acoustics problems appear to be much more widely accepted in Europe than in the U.S. This may be partly because the French R&D sponsors, at least in the acoustics and vibrations area, are relatively young compared to their American counterparts. Therefore, they are much more attuned to computer approaches through their educational backgrounds. This was especially true at one of the principal organizations funding acoustics research--Direction de la Recherche et Étude Technique (DRET), a defense research funding agency most comparable to our Defense Advanced Research Projects Agency. Here, the person responsible for the multimillion-dollar acoustics and vibrations program had recently graduated from an elite school with the equivalent of a masters degree in naval architecture and was in her early twenties.

In structural acoustics, I was very impressed by various programs of work being conducted at the Office National d'Études et de Recherches Aerospatiales (ONERA). Relevant work is conducted in both the Structures and the Physics Departments. Dr. R. Ohayon directs the Mechanics and Structural Calculations Group. Dr. Ohayon is vigorously directing efforts in structural acoustics and is especially interested in setting down the limits of applicability of large-scale computational programs devoted to the dynamic response of structures. He presently chairs a European Community action group that is addressing the problem of "Refinement of Structural Dynamics Computational Models." Such a cooperative program of industry and university computational models in the dynamics of structures users would be highly recommended for the U.S.

Other work at ONERA that merits U.S. interest is that of C. Soize who has been specializing in developing computational approaches for the midfrequency response of structures where the characteristics of the internally attached systems are not definitively known. Soize's approach uses a "master structure" which models in a deterministic fashion the outer smooth envelope or baseline structure. To this structure, one adds a "fuzzy structure" that can be described in terms of a set of added degrees of freedom whose mass and stiffness properties are only known approximately and described in a probabilistic sense. The response function of such a composite structure better mimics the response characteristics of realistic structures in the midfrequency range.

Recent meetings and journals of the Acoustical Society of America have had many high-quality French contributions. This is further evidence of the rapid strides the French have made in the last decade regarding acoustics research. In general, the French seem less chauvinistic about the use of their language, and more receptive to exchange of information with U.S. investigators than I had previously encountered. They seem to look forward to 1992 and the unified European Community with much more enthusiasm than the British. In fact, the "Société Francaise d'Acoustique" held its first conference on acoustics in Lyon on April 10-13, 1990. To make this meeting accessible to all Europeans, the official languages were both French and English. This is in marked contrast to meetings sponsored by a predecessor organization, the Society of French Language Acousticians. There are several other centers, including CNRS laboratories and university, where I believe high-calibre acoustics research is being conducted, but I have not visit them.

Acoustics Research in the Federal Republic of Germany

The FRG has a long tradition of being a world leader in acoustics research. At least two Fraunhoffer Institutes--the Institute for Hydroacoustics in Ottobruhn, and the Institute for Building Physics in Stuttgart--are devoted to various aspects of acoustics. The Ottobruhn facility is primarily devoted to defense-type studies in underwater acoustics, while the Stuttgart institute conducts research in problems more related to airborne and structureborne acoustics and generally to environmental acoustics.

The Institute for Hydroacoustics employs about a dozen scientists doing both theoretical and experimental work that is primarily funded by the FRG Ministry of Defense. Although the work is very high quality, I have not seen much of it published in the open literature. There is a bilateral exchange program with the U.S. at which much of the work of this institute is presented every 2 or 3 years. The institute maintains an experimental facility at Lake .\·nerzee, located southeast of Munich. This facility : somewhat limited in its measurement capabilit·· ompared to similar U.S. facilities, but it does have a unique facility consisting of a 1/8 scale model of a German-design frigate. Because of its heavy use as a recreational facility, the ambient noise levels in this lake are a less than ideal background levels in which to make measurements.

The Institute for Building Physics in Stuttgart has a large group of scientists doing research in the civil applications of acoustics. There are about 40-50 scientific workers with extensive laboratory facilities devoted to improving the acoustical environment within the home and work place. Professor Mechel, the leader, is world renowned and serves on many international standards committees on measuring and testing material properties of acoustic treatments. Also, he has been instrumental in establishing European-wide projects in these areas. The measurement capabilities at this institute are comparable to the best in the world for tests involving airborne acoustics. There are some unique facilities not equalled anywhere else, such as a semianechoic room, to measure the intrusive aspects of outdoor noise on the home environment. The design of their anechoic room is also somewhat unique in that the measurement platform is located in the middle level of the room, and not as close to the floor as in most facilities.

There are research groups scattered throughout the country concerned with transportation system noise. A very heated political debate is now looming about future high-speed rail transportation systems. The competition is between a magnetically levitated (MAGLEV) rail system capable of speeds in excess of 250 km/hr versus conventional high-speed rail system. The MAGLEV proponents claim their system is superior in terms of noise performance because of the lack of physical contact between car and rail. However, at the speeds considered, the aerodynamic noise generation problem could become the more important factor. The rival proponents are arguing the issue currently.

The Technical Institute of Acoustics in Berlin under the professorship of M. Heckl, has an internationally acclaimed research capability and is a training institution for FRG acoustics professionals (see ESNIB 89-10:2-4). There are other universities with similar capabilities, such as the University of Göttingen. Unfortunately, I did not visit them and therefore will not make any evaluative comments regarding their programs.

The British Institute of Acoustics

by David Feit

Introduction

The British Institute of Acoustics (IOA) holds an annual spring meeting that provides a regular forum for European acoustics.

The 1989 spring conference was held at Oxford University April 3-6. The organizer of the conference was Dr. H.G. Leventhall, Department of Environmental Engineering, the Polytechnic of the South Bank, London, U.K. This conference had approximately 150 participants, mostly from the U.K., Australia, Canada, Denmark, the Federal Republic of Germany (FRG), France, the Netherlands, and the U.S. Interestingly, the distinguished lectures at this conference were presented by two North Americans, born and educated in Europe and the FRG, respectively. The 1990 spring meeting was held in Southampton, U.K., on March 27-30. Dr. S. J. Elliot, Institute of Sound and Vibration Research (ISVR), University of Southampton, chaired and organized this very well-run conference. During the 1990 meeting, the official opening of the A. B. Wood Underwater Acoustics Laboratory was celebrated in a ceremony conducted by the university Vice Chancellor. Other technical visits that took place were a tour of the ISVR facilities, B&W Loudspeakers, and the IBM Science Centre. Approximately 200 people attended the 1990 meeting, most of whom again were from the U.K. There were about two dozen attendees from abroad with the largest proportion from the U.S., and two representatives from the U.S.S.R. In previous years, a fairly large French contingent attended, but that was not the case in 1990, even though the total number of attendees was greater than that of the previous 2 years. A meeting of the French Society of Acousticians was held in mid-April, and this may have kept the European (especially the French) attendance low.

The technical sessions are organized around themes and it is interesting to note the evolution from year to year and to see the increased attention given in 1990 to both underwater acoustics, and active control of noise in a variety of environments--reflecting perhaps the growth and increased application of this field in British industry.

1989 technical sessions were:

- Outdoor sound propagation
- Vibration and human response
- Physical acoustics and ultrasonics
- Aircraft noise
- Environmental noise
- Warning signals and behavioral response
- Instrumentation
- Student session with a variety of topics
- Open session

1990 technical sessions were organized around the following themes:

- Underwater sound
- Chaos in acoustical and vibrational systems
- Statistical energy analysis
- Barriers and enclosures
- Noise annoyance
- Laboratory calibration techniques, underwater acoustics
- Active control
- Noise and factories
- Musical acoustics
- Physical acoustics
- Noise and vibration transmission
- Student papers
- Open session

The European Community in general, I find, is very conscious of the quality of life, and the acoustical environment is an important component of this subjective evaluation. This is shown at technical meetings by the preponderance of papers devoted to the environmental impact of noise and its assessment.

I have found the student sessions, which are part of each IOA meeting, to be a very good idea. Young researchers are provided an opportunity to make presentations with others of similar experience. This is perhaps a less intimidating environment for these presenters, most of whom are probably making their first formal presentation to a professional audience.

As I have mentioned before with reference to these meetings, the manuscripts are put together in a short timeframe just before the meeting. The set is available to participants at registration and authors need only submit their papers a few weeks before the meeting.

During most of each 3-day meeting, four sessions were conducted in parallel. One must choose among several interesting papers, then scurry during the breaks between presentations. As usual, I will discuss only those papers that I heard and were most valuable to my interest--structural acoustics.

The 1989 IOA

The 1989 R.W.B. Stephens Lecture, presented by T.F.W. Embleton, National Research Council, Canada, was entitled "Review of Outdoor Sound Propagation-The Sound Field, Micrometeorology and Topography." H.E. Von Gierke presented the Rayleigh Medal Lecture on "Bio-Acoustical Reflections." These individuals are well known to American acousticians, both by the reputation of their research and through their long and dedicated service to the Acoustical Society of America (ASA).

Embleton's lecture was a review of the field of airborne sound emphasizing the effects of micrometeorology and topography on propagation. He began with a short history of the subject. First he discussed the early measurements of airborne sound speed made in the 17th century by Reverend Dereham, an Upminster minister. Then he noted that noises now generated by many modern conveniences give rise to significant social and political problems.

The technical issues discussed were those of molecular absorption and propagation over the ground surface when it is characterized by a surface impedance. In this context, he mentioned Sommerfeld's work on electromagnetic wave propagation and the sign error he made in his early work. This precluded the existence of a trapped surface wave propagating along the air-ground interface, which can exist under certain circumstances. This particular aspect of the problem also was the major focus of the paper presented later in the meeting by F. P. Mechel, Fraunhoffer Institut-für-Bauphysik, Stuttgart, FRG. I was particularly interested because of its relation to a controversy of the late 1970s in the structural acoustics literature. In the latter, the discussion revolved around the existence of additional surface waves on a water-elastic plate interface other than the subsonic water-loaded flexural wave expected from the familiar structural-wave theory relevant to the vibrations of plates *in vacuo*.

The remainder of Embleton's talk reviewed much of the recent modeling efforts in this field. In particular, he gave a concise overview of the work related to measurements and modeling of the ground impedance, a crucial factor in airborne sound propagation. His talk was an excellent introduction to the three technical sessions devoted to this subject.

Rayleigh Medal Lecture. In this talk, Von Gierke gave a history of the effects of mechanical vibrations and sound on the human body. In doing this, he presented this history in terms of his own involvements in the field beginning with a study of whistling by the human mouth which grew out of work he did on sound radiation by circular jets. To examine sickness produced by ultrasound, he considered the absorption of sound on human surfaces, and characterized the body impedance in the various frequency regimes. He then discussed different biodynamic models that were developed in his laboratory. In his final remarks, he mentioned that there was no answer yet to the question of the nonauditory health effects of noise.

Outdoor Sound Propagation. Of all the subjects mentioned in the introduction that had special sessions devoted to them, this was be the area I was most interested in. Many of the papers presented had several authors in common, suggesting that they have a great deal of influence on this particular specialty within the U.K. These individuals are: K. Attenborough, Open University, Milton Keynes, U.K.; D.C. Hothersall, University of Bradford, Bradford, U.K.; and S.N. Chandler-Wilde, Coventry Polytechnic, Coventry, U.K. Attenborough has written papers in this subject since 1980 (Attenborough, 1980), and Chandler-Wilde wrote his doctoral dissertation in the field (Chandler-Wilde, 1988).

A paper entitled "Acoustic Scattering By Sub-surface Inhomogeneities," by D. L. Berry, S. N. Chandler-Wilde, and K. Attenborough, cited the U.S. Army European Research Office as its funding source. This paper dealt with the application of boundary integral equation methods to the prediction of the acoustic field caused by a point source in a quiescent atmosphere, above a homogeneous rigid-porous half-space in which a rigid inhomogeneity is situated. The rigid-porous half-space is characterized as a scalar medium in which the field satisfies the usual Helmholtz wave equation with a complex characteristic impedance and a complex wave number.

In another paper, Y. Chen and K. Attenborough studied interface waves on an air/air-filled poroelastic media interface. Here the poroelastic media is characterized by the Biot theory (Biot, 1956). The dispersion equation obtained by satisfying the boundary conditions at the interface is solved numerically to determine the surface wave phase velocities and attenuation curves as a function of frequency. For a two-medium system, the surface waves are found to be almost nondispersive, while a three-medium system has surface waves that are dispersive.

The attenuation produced by barriers was the subject of a paper by Hothersall, Chandler-Wilde, and M. N. Hajmirzae. The authors use the boundary element method to calculate the insertion losses obtained using a range of single-barrier forms. They assume that the results obtained from a two-dimensional modeling of the situation is adequate to indicate the relative performance of different barrier forms. Their approach also allows them to vary the cover treatment of the barriers by performing the calculations with differing wall admittances.

In a later session devoted to the same subject, Mechel presented his paper entitled "Analysis of Spherical-Wave Propagation Over Absorbing Ground." I have already referred to this paper in my discussion related to Embleton's review paper, but I feel it warrants further attention because of several strong statements the author made. These are further elaborated on in a forthcoming book (Mechel, 1989).

For one, he claims to end the controversy over the question of the existence of the air/ground-interface surface wave in airborne-sound propagation. He summarizes the situation by saying that, "The existence of surface waves can be shown in principle, their importance in a concrete situation is still open." He contrasts this with a statement made by Habault and Filippi (Habault, 1981) who say that the surface wave is nothing more than a mathematical artifact arising from a special method of approximation and does not appear in their own numerical solution. Mechel concludes that the ground surface impedance must have a spring-like impedance term for the surface wave to exist.

He also takes issue with those who claim that Rudnick was the first to translate the electromagnetic solutions to acoustical sound fields (Rudnick, 1947), instead giving credit to Schuster (Schuster, 1939) who treated the propagation of airborne sound over a porous half-space. In this paper, he also presents direct numerical solutions based on exact formulations, which he rightly claims are the ones to which any approximate theory is to be compared. To justify this, he discusses cases where various approximations are compared to each other with no reference to results calculated from exact theories.

Aircraft Noise. Rather than leave you with the impression that the only talks of interest were in the field of outdoor sound propagation, I shall move on to other talks I heard that caught my attention. One of these, a joint paper by N. Peake (presenter) and D. Crighton of Cambridge University, U.K., developed an asymptotic theory of propeller noise in the near field. This work is sponsored by Rolls Royce and will become increasingly more important as high-efficiency, propeller-driven aircraft become more popular. The most likely configuration will consist of two sets of counter-rotating propellers, each with many blades. Although the advance speed of the propellers will be subsonic, the tip speeds of the rotating blades may be supersonic.

The approach used by these investigators is that of modeling the radiated pressure fields as the solution to the nonsteady wave equation driven by nonstationary sources, which may be monopole-, dipole-, or quadrupole-like. The solutions are then represented as integrals whose asymptotic limits in the near-field are obtained. The chord lengths are assumed small in comparison to the span of the blades. Although not presented here, the asymptotic expressions will be compared to more exact results obtained from numerical integration.

In another paper by Crighton and a student, P.W. Hammerton (presenter), they discussed the use of approximate schemes in solving nonlinear acoustic problems. Here they employed asymptotic and numerical techniques to study the evolution of cylindrical and spherical acoustic waves subject to thermoviscous dissipation. A more complete version of the paper has now been published (Hammerton, 1989).

F. Fahy, Institute of Sound and Vibration Research (ISVR), University of Southampton, U.K., presented a very nice summary paper on the applications of reciprocity principles to acoustical and vibro-acoustical problems. In his introduction, he credits Lyamshev for recognizing that reciprocity techniques can be applied to those problems that involve the interaction of elastic plates and shells vibrating in the presence of contiguous fluids. Fahy refers to these problems as "vibro-acoustics," whereas we in the U.S. have recently called them "structural acoustics." The specific applications discussed were: the application to duct mode directivity measurements, the radiation directivity of a force-driven submerged body, and some recent work on cabin noise in propeller-driven aircraft. The ISVR is using the technique to study model airplane fuselages as transducers of the external pressure fields to eventually be able to evaluate noise control features introduced in aircraft design. He concludes, as we would all agree, that reciprocity can, in some cases, allow measurements to be performed more conveniently and at times even more accurately.

1990 IOA

R. W. Stephens Lecture. The 1990 R. W. Stephens Lecture (seventh of the series) was presented by J. M. Bowsher, University of Surrey, Guildford, U.K. His subject was a "Personal View of Musical Acoustics." His thesis is that musical acoustics is the mother of all acoustics and he feels that all branches of acoustics can be traced back to musical acoustics. He demonstrated his thesis during a very entertaining hour-long discourse on the subject starting with a critique of Pythagoras' work on the mathematical explanation of the musical scale, and the vibrating string. I was amused with his story of discussions with the Science and Engineering Research Council (SERC), the principal funding agency for basic research in the U.K., similar to the National Science Foundation. When appealing for funds from SERC for an acoustical research program, he was told that the work was not necessary since the basis of the work had been done before by Rayleigh. (I am sure U.S. researchers have heard similar remarks on certain occasions.) He responded by saying that "... much of the work done at

CERN had been anticipated by Lucretius and wasn't it time they ran down their enormous contribution to that organization and spared some money for those of us doing new physics." Regretfully, the SERC did not take his advice.

Tyndall Medal Lecture. N. G. Pace, University of Bath, U.K., was awarded the Tyndall Medal for his contributions to underwater acoustics. The topic of his lecture was "Acoustic Backscatter and Sea Bed Characteristics." Pace reviewed the theoretical basis and experimental studies directed toward rough surface backscatter and showed how such measurement can be applied to sea bed sensing. The impression I got was that this material was fairly well known and that this particular contribution was a review of work done some time ago.

A.B. Wood Medal Lecture. "Flow Noise" was the title of the talk given by A. Dowling, Cambridge University, who was this year's winner of the A.B. Wood Medal. Ann is very well known to many of us in the U.S. through her participation as a lecturer, together with S. Ffowcs-Williams, D.G. Crighton, and F. Leppington, in the Hydroacoustics short course given at several U.S. locations in the last few years. This course or a slight variation has also been given in Italy and the U.K. in the last 2 years. Her lecture gave a comprehensive review of the subject--showing it as the most significant source of undesirable noise heard by a shipboard-mounted sonar system. First, she presented some classical results of the hard-walled pressure spectrum as derived both theoretically and experimentally by various authors. These results were then used to predict the effects on a domed sonar system looking specifically at the effects of mean flow, flexible surfaces, and coatings. She ended her discussion by examining wavenumber conversion caused by the finite size effect of the transducing surfaces. Her final conclusion was that for steel plates at reasonable frequencies, the convective peak does not appear to be a significant source of low wavenumber-pressure fluctuations.

Chaos in Acoustical and Vibrating Systems. On the first morning, I had to choose between sessions on chaos, statistical energy analysis (SEA), and underwater sound. I begin with two papers on chaos. The first invited talk was by J.M.T. Thompson, University College, London, who talked about "Chaos and Fractals in Vibrating Systems." Thompson talked about a renaissance in the study of nonlinear dynamics that has come about with the increased use of computers in the last few decades. In fact, he states, "classical analysis has ground to a halt," a statement which I am sure would, in other circumstances, provoke a major discussion. In this talk, Thompson gave a brief introduction to the geometrical concepts of nonlinear-dissipative systems, and then showed some new results related to the erosion of the safe-basin boundary in driven oscillators related to the escape from a potential well. These concepts are relevant to the design of basic engineering systems such as the rolling of ships in a dynamic seaway. He states "the erosion of the basin of attraction leads to a loss of engineering integrity." Thompson recently published a book (Thompson, 1986) from which most of the material presented was taken. During the discussion period, W.G. Price, at the time from Brunel University, but now Professor of Ship Dynamics at Southampton, asked Thompson how to distinguish between algorithmically generated chaos versus that which truly arises from the modeling of the system. Thompson responded that the question was indeed a very deep one, but that the notion of chaos has been demonstrated using a variety of different machine implementations using the same algorithms. Furthermore, physical evidence on real systems does exhibit chaotic behavior in specific parameter ranges.

The second invited talk in this session was by J.D. Abrahams, University of Newcastle Upon Tyne, U.K., entitled "Complex Motions of a Fluid-Loaded Nonlinear Elastic Plate; Periodic, Subharmonic and Chaotic Vibrations." Abrahams discussed the situation of a baffled elastic plate in a compressible medium subjected to forcing of sufficient magnitude so the nonlinear inplane forces in the plate cannot be ignored. He demonstrates that if an acoustic-plane wave having two nearly coincident frequencies irradiates the plate, its deflections can exhibit harmonic-, subharmonic-, or aperiodic-(chaotic-) time variations depending on the nonlinearity parameters used in the analysis.

Statistical Energy Analysis. The first talk in the SEA session by J.M. Mondot of ACOUPHEN, France, certainly had an intriguing title--"SEA, a Comeback?" I couldn't attend because of a conflict, but even more unfortunate is that it was not included in the proceedings, and so I cannot comment on the paper.

A.J. Keane, Brunel University, Uxbridge, U.K., and W.G. Price (mentioned earlier in this report) reported on "Exact Power Flow Relationships Between Many Multi-Coupled Multi-Modal Sub-Systems." In previous studies, they derived and used exact power flow results for a pair of multimodal systems coupled by a spring at a single point. The paper presented here gives the theoretical basis for relaxing the most severe of the above restrictions. Namely, it allows for an arbitrary number of subsystems coupled in an arbitrary manner. The objective is to quantify the deviations from the mean-power flows predicted by SEA analyses where there are restrictions on the coupling details. This particular approach uses the Greens Functions for the uncoupled subsystems which are the only ones available when actual problems are tackled. The approach is similar to that used by Langley (Langley, 1989), who presented his ideas in a later talk.

The next paper, "A Study of Uncertainty in Applications of Statistical Energy Analysis to One-Dimensional and Two-Dimensional Structural Systems," was by Adnan Mohammed and F.J. Fahy, ISVR. This work was sweeping in its coverage. The paper attempt to address several fundamental issues regarding the applicability of SEA. The critical questions raised are: "What are the criteria to quantify the reliability?" (of the SEA estimates), and "What certainty is associated with the prediction of response when using this approach?"

Their research program's principal objective was to study the uncertainty of the SEA predictions when subsystem geometries are perturbed. The systems analyzed consisted of two long, steel cantilever beams coupled at their free ends by a damped translational spring (nonconservative coupling), and two rectangular flat steel plates coupled by an elastic nonconservative element. The opposite edges are simply supported. The results presented compare estimates of the coupling loss factors derived from a traveling wave approach (two semi-infinite systems) to those of an SEA approach as a function of modal overlap. For low modal-overlap, factors the differences are large and much more sensitive than the power flow. Experimental observations support the conclusions.

R.S. Langley, College of Aeronautics, Cranfield Institute of Technology, Cranfield, U.K., presented "An Approach to the Derivation of the Statistical Energy Analysis Equations." This study's objective was to rederive the SEA equations based on a continuum analysis of a general coupled-dynamic system. He shows that the general form of the SEA equations is widely applicable if a suitable energy definition is adopted. He also derives new expressions for the coupling-loss factors in terms of the Greens Functions of the system. Furthermore, the concept of weak coupling does not guarantee that nondirect coupling-loss factors (coupling from other than nearest neighbor systems) can be neglected. However, it is likely that this condition is valid for weakly-coupled reverberant systems.

I returned to SEA after the lunch break. J. Woodhouse (speaking for himself and coauthors M. Blakemore, B. Jeffries, R.J.M. Myers, all affiliated with Topexpress, Ltd., Cambridge, U.K.) presented a paper on the application of SEA to cylindrical structures. For this study, contracted for by the Royal Aerospace Establishment, they constructed a test structure made up of sections of a cylindrical shell typical of aerospace structures. The sections are all different lengths, but the joints between the sections are of identical design. The structure will be used for a variety of studies exploring different aspects of SEA modeling of vibration levels within the structure. The experimental configuration and proposed experiments were carefully explained. Investigators from the U.S. who are interested in SEA modeling should follow very closely the progress of this very fundamental piece of structural acoustics research. In the initial testing, it was found that the dispersion curves for individual sections of the shell are very well explained by currently available shell theories (Hodges, et al, 1985).

Underwater Acoustics. To round out my morning, I scurried to the Underwater Acoustics session to listen to two papers. The first one by P. Dobbins, British Aerospace, Bristol, U.K., considered the effects of seawater inhomogeneity on the plane-wave spectrum and, ultimately, array directivity. The paper presented a new method for obtaining the average directivity pattern of an array subject to correlated phase and amplitude fluctuations. These are related to the plane-wave spectrum of the fluctuating wave field. The results allow one to obtain a reasonable estimate of the best angular resolution achievable from a sonar array.

The other paper dealt with "Enhanced Propagation in a Foamy Medium," and was contributed by T.V. Gedrich, C.H. Harrison, and A. Cowley. The first two authors are from YARD Ltd., London, U.K., and the other author is from the Admiralty Research Establishment, Portland, U.K. The paper describes a new prediction program SWARM, which is used to model propagation and scattering within bubble clouds. According to the authors, it has greatly improved the understanding of propagation through foamy media, and has provided a convincing explanation of the propagation anomalies along and across wakes.

Numerical Methods Applied to Structural Acoustics. The Open Session had a few papers that interested me. One dealt with "Finite Element Method Analysis of Sonar Transducers," by S.S. Jarng, B.V. Smith, and J.R. Dunn, School of Electronic and Electrical Engineering, University of Birmingham, U.K. Their main objective was to outline the development and validation of piezoelectric "brick element" as a part of a program to develop software for SONAR transducer design. In France during the past decade, a group also developed a software package of this type; the software is known as ATILA.

J.S. Bolton, School of Mechanical Engineering, Purdue University, West Lafayette, Indiana, gave a paper coauthored with T.J. Wahl on "The Use of the Discrete Fourier Transform to Calculate the Spatial Response of Damped Panels." The formal solution of such problems is traditionally given in terms of Fourier Transforms. These transforms must, however, be inverted to obtain the physical solutions. Here the authors show how these inversion integrals may be obtained efficiently and "exactly" by using Fast Forier Transform algorithms. He claims that this is the first time that such an approach has been used to calculate the response of fluid-loaded plates.

This is not the case, however, since this same technique has been used and discussed by Vogel and Feit (Vogel, 1977). The authors expect to use this technique to study a variety of multielement-damping treatments not amenable by conventional damping theory.

Active Control. Three sessions of the meeting were devoted to active control with fewer than two dozen papers presented. Most of the work came from the U.K., but there were several papers from the U.S., France, the FRG, Sweden, and Japan.

Immediately following is an article dedicated to active control in engineering systems. That article reviews most of the work presented here in more detail, as well as other efforts. Rather than be repetitious, I discuss some other work presented at the meeting which will not be reported on elsewhere.

Concluding Remarks

The 1989 conference was the second consecutive IOA meeting that I attended. I find that the quality of the work was first rate and extremely well presented. The 1990 meeting, was similarly extremely well organized and offered an excellent sampling of acoustics work being currently performed in the U.K. and Europe. The quality of the investigations and the mode of presentation were uniformly high quality. Because the meetings are so much smaller in size and scope compared to an ASA meeting, one can come away with a good sense of where and who is doing the really significant acoustics research in the U.K. The practice of publishing written versions of the presentations with very short deadlines is one that should be investigated and considered by the Acoustical Society of America. I think that this helps produce much better preparation, organization, and communication of the ideas of the authors.

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The Applications of Active Control to Engineering Systems

by David Feit

Introduction

Active control applied to engineering systems is an area being vigorously pursued within the European Community. In the 30 months that I worked at the Office of Naval Research European Office (ONREUR), I saw and heard many references in the public media to the use of active control in automobiles and airplanes to lessen the impact of noise annoyance. Some of these were reported on at many of the technical meetings that I attended. I also discussed the subject with investigators active in this field. I only refer to them to demonstrate that in Europe active control seems to be emerging from the recesses of scientific laboratories into the light of public attention. During a recent television broadcast on new developments shown at the "Farnborough '90 Air Show," an active vibration control system was mentioned. The system was installed on a new 20-seat Westland helicopter that will be used to ferry passengers.

In view of such evidence, ONREUR and the Office of Naval Research (ONR), Arlington, Virginia, decided to jointly sponsor a workshop on the subject. This special topic workshop was held on June 8, 1990, in the Peterhouse lecture hall at Cambridge University. The objective was to bring together experts from Europe so that they would share with the group their current achievements and their views of potential developments. The time was chosen to coincide with the presence in Europe of ONR personnel and contractors also engaged with this topic.

Prof. Sean Ffowcs-Williams, Cambridge University, Department of Engineering, and I cochaired the meeting. Ffowcs-Williams is a principal spokesman for the use of active control in a variety of engineering applications. He is well known by the U.S. and European investigators dealing in the workshop. Attendance was limited to 30 people. (See Appendix for a list of attendees, addresses, and their particular interests.)

Cambridge University provided the facilities and the Cambridge Philosophical Society contributed financially. Following the welcome and introduction to the workshop by Prof. Ffowcs-Williams, the program consisted of statements by the invitees related to their own work in the field. Because of the many invitees wishing to make statements, they were limited to about 10 minutes each. This took up the entire morning and the beginning of the afternoon. The remainder of the afternoon was devoted to discussion. This report summarizes the presentations and discussions of the workshop.

ONR-Supported Active Control Work

The actual presentations began with Dr. R. J. Hansen, ONR headquarters,who gave a brief overview of the work being sponsored by ONR both within the U.K. and in the U.S. The area of turbomachinery instabilities work is now being conducted by Topexpress, Ltd. of Cambridge, U.K. The problem that they are investigating is overcoming the effects of surge instabilities in compressors. This can have an important payoff in extending the flow range and performance of compressors. For a related problem; i.e., rotating stall wherein a small disturbance can grow into periodic distortions in a multistage compressor, Hansen reported that the Massachusetts Institute of Technology/Cambridge effort directed by Prof. A. Epstein has achieved success.

The ONR program also supports efforts in combustion. The objective is to achieve enhanced energy release, the extension of flammability limits, and the suppression of flame instabilities. For this work, investigators led by Dr. K. Schadow, Naval Weapons Center, China Lake, California, have set up experimental facilities and developed numerical simulation capabilities. Hansen reported that they have obtained good qualitative comparisons between experimental and computed results using large eddy simulation. With the numerical simulation, they can introduce the effects of a control algorithm and observe the results. This work has also motivated research in the areas of a priori systems identification, noise processes, and neural network architecture.

Also, ONR supports work in what is called fuzzy logic-based fault identification procedures that will be applied to processes incorporating many sensors and actuators. In this approach, a comparison of the histograms of the operating parameters with that of stored histograms of failed components made to identify a fault.

Other activities mentioned were the use of linear fractional transformations for system identification, and electromagnetic scattering control for simplified geometric shapes. Hansen revealed that the projects are funded by a $3-million, 5-year program

Cambridge University Activities

Many workshop presenters are connected with the Cambridge University Department of Engineering. This is probably a result of Prof. Ffowcs-Williams' efforts. He has been at Cambridge since 1972 and has been a very forceful and persuasive advocate of active control technology. Many of the investigators currently pursuing this technology have studied at Cambridge or worked with him while he was associated with Topexpress, Ltd.

During this presentation Ffowcs-Williams gave a history of the active control projects he has been involved with over the last two decades. In the early applications, the approach used was that of controlling sound fields by interposing a phase inverted replica of the source field in the regions of interest thereby reducing the unwanted noise by wave superposition. These techniques were originally introduced in the laboratory and then applied in some field demonstrations. One of the earliest and most successful demonstrations of this technology was the quieting of the low-frequency noise emissions of a gas turbine pumping station at Duxford, U.K. In this application, 72 large loudspeakers consuming about 1 kilowatt of electrical power were able to attenuate the lowest octave of noise by about 15 decibels (dB). The gas turbine itself was a 40 megawatt machine.

Other more recent field applications and demonstrations have been in reducing cabin noise of propeller-driven aircraft. In this application, a team of scientists from the University of Southampton's Institute of Sound and Vibration Research (ISVR), as well as one from Topexpress Ltd., both reported excellent results.

Ffowcs-Williams has more recently been involved with the use of active control in compressor instability problems mentioned earlier. His interest in this application area arose several years ago when Ffowcs-Williams spent a long time at the MIT Department of Mechanical Engineering collaborating with Prof. A. Epstein.

The work in surge control initiated by Ffowcs-Williams is now being executed at Topexpress, Ltd. under an ONR program. Dr. M. Harper, Topexpress, Ltd., presented some of the details of this work. Work is continuing on narrow-band surge control using a Rover IS-60 test engine. He stated, however, that surge can be induced from a normally just-stable operating point by single frequency forcing at all frequencies up to at least 60 Hz. The problem is therefore a broadband control problem that requires a purpose-built control system. This is the current effort being pursued by the ONR/Topexpress project. They reduced continuous surge to occasional single cycles, and they are now applying multichannel control to an engine.

Dr. Ivor Day, Whittle Laboratory, Cambridge University, U.K., discussed the work he is doing on the active control of rotating stall. In his test rig, he is using a four-stage compressor that is highly loaded. For control, he is using 12 controllable air injection valves. Air consumption, all open, is about 1 percent of the total airflow. With this setup, he has demonstrated that active control of rotating stall surge is a reality, and can be useful in preventing stall inception and stall recovery once it occurs. Although this demonstration has been performed on an actual compressor, the setting is still in a laboratory.

Dr. C. Freeman, Rolls Royce, Ltd., discussed applications to real engine problems. Because of his position within a commercial setting, he could not discuss the problem at the same level of detail as those from universities. We did learn, however, that Rolls Royce is pursuing this technology fairly vigorously using in-house as well as outside consultants. Moog Controls, a U.S. valve manufacturer, has been retained for the design of hydraulic actuators. The control algorithms are being considered by M. Swinbanks, MAS Research Ltd., Cambridge, U.K., and Ivor Day and Ann Dowling have been retained as consultants. The applications being pursued are control of afterburner buzz, and control of rotating stall in a Viper engine. Experiments from the latter test were being run at the time of the workshop, and were therefore not available at the meeting. From the discussions presented, it appears that Rolls Royce is making a very serious commitment to using active control technology and is attempting to demonstrate it in a commercial environment.

Dr. A. Dowling described in detail her laboratory demonstration of the use of active control for the reheat buzz problem in the afterburners of jet engines. She collaborated with P.J. Langhorne, University of Otago, Dundee, New Zealand, and N. Hooper, Cambridge University. The phenomenon of reheat buzz is attributed to a low-frequency combustion instability of a flame burning in a duct and exciting an acoustic resonance. This instability has been controlled by using about 3 percent more fuel, but the engine can achieve some 10 percent increase in thrust. The acoustic energy in the 0-440-Hz band is reduced to 18 percent of its uncontrolled value.

Another representative of the Cambridge school of active control specialists is Dr. M. Swinbanks, MAS Research Ltd, Cambridge, U.K. I believe this company is a one-person consultancy operation. He presented the historical development of active control of dynamical systems. Here is a useful list to put the technology in perspective.

- Ship stabilizers
- Aircraft stabilizers
- Controlled startup of unstable chemical/nuclear plant
- Flexing aircraft and spacecraft structures

- Plasma confinement
- Very low-frequency vibrations (hull flexure caused by main propulsion)
- Single degree of freedom sound in ducts
- Ground-based gas turbine exhaust silencing
- Multiple-mount vibration control
- Unstable combustion processes
- Multi-degree of freedom aircraft cabin modes
- Aero-engine compressor instabilities

These applications have become progressively more complex because of the increasing speed of response, reduced length scale of the controlled system, and the increasing complexity of detail. A review of Swinbanks' achievements in the field reveals his involvement with many of the applications mentioned above. He presented a graph showing that the achievable performance in a 20-mode environment should be now in excess of 20 dB. The only constraint considered, however, is the available processing power. He did not talk about the limitations imposed by the performance of the actuators, which is now considered to be a major stumbling block in the applications of the technology.

The last speaker of the Cambridge school was Dr. C. Ross, 2020 Science Ltd. Cambridge, U.K. Ross, formerly of Topexpress, Ltd., has combined forces with Dr. G. Eatwell and Dr. A. Langley to form this company solely dedicated to commercially exploiting active control technology. 2020 Science is now a wholly owned subsidiary of Noise Cancellation Technologies, Inc., and operates as NCT (UK) Ltd. They are researching in cabin noise control, active engine mounts, control of turbine shaft whirl using magnetic bearings, and structural controllers.

Other U.K. Contributors

Many significant active control projects are being pursued at or associated with the University of Southampton Institute of Sound and Vibration Research. Dr. S. Elliott talked about the system developed as a joint project with British Aerospace to actively control propeller-induced passenger cabin noise. This system uses 32 detectors at the seated head height of passengers and 16 detectors--half at floor level and half at the baggage rack level. The reduction results using various combinations of sources and detectors and different conditions were shown.

Dr. P. Nelson talked about the project with Lotus Engineering that addressed the active control of automobile noise. The problem considered here is that of single frequency engine firing noise in the 100-200-Hz range and is sometimes referred to as "boom." At an earlier meeting held at ISVR I experienced the on/off behavior of such a system in a car fitted with a prototype working through the car entertainment center (radio speakers). They are also trying to address the problems of random noise in automobiles such as that induced by road roughness.

A. Staples, Westland Helicopters, spoke about their Active Control of Structural Response (ACSR) system. This system has been developed to alleviate structural vibration problems in helicopters. The system was first demonstrated successfully in February 1987 using actuators installed at the gearbox raft interface with the helicopter hull. Moog Controls developed the actuators. Another type of system is being designed for their EH101 helicopter. (As mentioned earlier, it is now being installed in operational vehicles.

I. Roebuck, Admiralty Research Establishment, Portland, U.K., represented the Royal Navy. He discussed the potential usefulness and problems associated with the technology in naval applications. He stated that the technology has potential in vibration isolation mountings and as an alternative to adaptive beam forming for the self-noise problem. Of course, one also can visualize the potential for reducing acoustic radiation in specific directions. In such an environment, the systems must be fail safe. He pointed out the psychological problems related to the fact that such systems can lead to over confidence and a lack of attention to the passive systems that help make the ship so quiet in the first place. He also mentioned the problems that may arise because of the wrong choice of actuator locations and the possibility that in a system failure, the system may become a broadcaster rather than a silencer. One must also remember that there is an inherent maximum achievable control for time-varying systems.

French Contributions

The first French speaker was Prof. S. Candel, University of Paris, France. His work emphasizes the understanding of the fluid mechanics of combustion and the control of instabilities in the process. His work in control began after Ffowcs-Williams introduced the notion of instability control. He uses active control to study the mechanisms leading up to instabilities. The photographic process he uses allows him to probe a test section of about 10 cm. high by 30 cm. long. He is now using more advanced adaptive techniques in his experimental setup.

There is also related work going on at Imperial College, London, supervised by Prof. J.H. Whitelaw. Dr. S. Sivasegaram, Department of Mechanical Engineering, described the work on the active control of oscillations in pre-mixed flames. They have concluded that knowledge-based control results in an improvement in attenuation of pressure oscillations.

Dr. G. Bioulloud, École Centrale, Lyon, France, reviewed active control work in France. The project at the École Centrale deals with local control in three-dimensional fields, with the approach of minimizing the field at N points by using (N + 1) sources or actuators. A joint project with French Aerospace Research Institute (ONERA) and Aerospatiale relates to the control of low-frequency aircraft cabin noise using mode synthesis. He showed results measured on the Concord cabin using a shaker as the controlling source and a loudspeaker as the source. The other work he covered is outlined in Figure 1. Specific discussions describing for all the investigations discussed can be found in the attached list of references. Based on his presentation, there appears to be a fair amount of activity in this field within France.

Bioulloud's colleague, Dr. M.A. Galland, discussed in detail a joint project in which they are considering the adaptive active control of natural flow instabilities. In the particular examples cited, they are looking at a problem of surge and the control of oscillations in flow-excited cavities. In both of these systems, it appears that they are considering one degree of freedom systems.

German Contributions

Dr. J. Scheuren, Muller BBM GMBH, Munich, Federal Republic of Germany (FRG), discussed work in which he applies control techniques to problems in structure-borne noise, and more specifically to flexural vibrations on a beam. The flexural vibrations of a beam differ from freely propagating airborne acoustic waves because of their dispersive nature. He looks at the free vibrations of a beam at resonance as an instability. His talk showed both theoretical and experimental results for both a beam and for active isolation mounts.

Prof. P. Hagedorn, Mechanics Institute, Darmstadt, FRG, also talked about active vibration control applied to structural problems. He mentioned that all car manufacturers are working on control applied to auto suspension systems, in which the automobile is typically represented as a 10-20 degree of freedom system. Other areas of consideration are the protection of buildings against earthquake damage, flexible robot arms, and space structures. He mentioned the problem of "spillover" in which the controlling forces contaminate higher-order modes thus degrading the degree of control that can be achieved. In his own work, he has been considering much simple systems such as strings and beams that are essentially one-dimensional systems. In this context, he discussed controllers, in this case shakers, which he called "energy valves."

Because they were limited to the presenters' own works, these two discussions did not give a complete picture of active control efforts within the FRG.

Conclusions

Based on the nationalities of the attendees and the presentations, one gains the impression that most of the European work on the uses of active control in engineering systems is taking place in the U.K., with France following closely behind, and a lesser amount in the FRG. This conclusion must be tempered by the fact that the meeting took place in the U.K. Therefore, it was much more accessible to U.K. participants, and their work more readily available to the organizers. However, we must also note that much of the early promotion of the field was generated in the U.K. Pre-eminence in the field may also possibly be ascribed to the fact that the U.K. is very strong in computer technology, a very necessary basic building block to active control systems.

During the discussion period, Ffowcs-Williams raised a question related to management of the processing and complexity of the systems that arise as we move to controlling systems with many more degrees of freedom than the current applications. Swinbanks responded saying that in the past the principal constraint was that of processing power, but this was no longer the case. He cited the case of reducing aircraft passenger cabin noise which has now been addressed successfully by three different groups. He believes that strong commitments of industrial resources will inevitably lead to success. Another area that he was optimistic about was that of passive materials whose performance can be enhanced by the addition of active control concepts.

A question arose on the issue of nonlinearities in the systems considered. Dr. R. Barron, Barron Associates, Standardsville, Maryland, responded that parallel processing computer architecture offers the potential of addressing this problem. S. Elliott commented that an increasing number of channels adds robustness to the system since the loss of a lesser number of channels becomes less significant. Staples said that the computer capacity that now exists already exceeds what can be used in a practical situation. Here I noted some disagreements, with the academics generally saying that enhanced and faster computer capabilities should be pursued, with the applications engineers saying that such capabilities were already more than necessary.

Ffowcs-Williams changed the subject somewhat by saying that all the applications currently being considered were not very realistic (in his words, they were "Mickey Mouse problems"). C. Freeman, Rolls Royce, agreed that academia has demonstrated control in slow and simple machines, but questioned whether it is yet possible to control the growth of instabilities. In his mind, 60 percent of the problem is gaining a better understanding, 20 percent is developing improved actuators, and 20 percent is the actual implementation. Related to the issue of actuator development, A. Dowling stated that phase accuracy is more important than amplitude control. A general comment that seemed to be agreed to was that market forces would foster the necessary improvements to actuators, and that research resources would be better spent elsewhere.

Another conclusion was that the prospect of active control has driven industry to try harder to control noise at the source. This can be considered as a beneficial fallout of active control development. C. Ross offered the idea that active control has helped us gain a better understanding of the systems we are seeking to control.

Future areas in which the field is likely to have impact are among others boundary layer control: vibration control in large space structures, bluff bodies wake control, and the development of "smart structures."

In conclusion, J. Hansen ended the meeting by thanking the speakers and the audience for their participation, and stating that the meeting had met its objective of presenting ONR with a status report on European efforts in the field. Furthermore, in his opinion, the U.S. is somewhat behind in actually using active control techniques in realistic engineering environments.

Based on my observations, both at technical meetings and reading the public media, and accounting for the differences in total research and development funding, I have to agree with him.

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Appendix

Active Control Workshop Attendees

Name	Address	Interest
Dr. Roger Barron	Barron Associates Inc., Route I, Box 159, Standardsville, VA 22973-9511	Control theory
Dr. G. Biolloud	École Centrale De Lyon, 36 Avenue Guy de Collongue, BP 163, 69131 Ecully, Cedex, France	Active control developments in France
Dr. G.L. Blankenship	Technel Sciences Inc., Suite 620, 7833 Walker Drive, Green Belt, MD 20770	Control theory
Prof. S. Candel	École Centrale des Arts Et Manufactures, Grande Voie des Vignes, 92295 Chatenay, Malebry, Cadex, France	Active combustion control
Dr. A. Cargill	Rolls Royce plc, P. O. Box 31, Derby, U.K. DE2 8BJ	Engine stall control
Dr. I. Day	Cambridge University, Engineering Department, Whittle Laboratory, Madingly Road, Cambridge, U.K. CB2 1PZ	Active suppression of rotating stall
Dr. Ann Dowling	Cambridge University, Engineering Department, Trumpington Street, Cambridge, U.K. CB2 1P	Control of reheat buzz
Prof. J. Doyle	California Institute of Technology, Dept. of Electrical Engineering, Pasadena, CA 91125	Control Theory
Dr. S.J. Elliot	Institute of Sound and Vibration Research, Southampton University, Southampton, U.K. S09 5NH	Control of Random sound
Dr. David Feit	Office of Naval Research European Office, 223/231 Old Marylebone Rd., London NW1 5TH	Control theory
Dr. C. Freeman	Rolls Royce plc, P. O. Box 31, Derby, U.K. DE2 8BJ	Engine surge control
Dr. M.A. Galland	École Centrale De Lyon, 36 Avenue Guy de Collongue, BP 163, 69141 Ecully, Cedex, France	Control of flow instabilities
Prof. P. Hagedorn	Institute für Mechanik, Technische Hochschule, Hochschulstrasse 1, D-6100 Darmstadt, Nr. Munich, FRG	Vibration control
Dr. R. J. Hansen	Code 121, Office of the Chief of Naval Research, 800 North Quincy St., Arlington, VA 22217-5000	Research management
Dr. Mark Harper	Topexpress, Ltd., Poseidon House, Castle Park, Cambridge, U.K.	Feedback filters for surge control
Dr. Eric Hendricks	Code 634, Naval Ocean Systems Center, San Diego, CA 92153-5000	Research manager
Dr. David Moore	Department of Engineering, University of Cambridge, Trumpington Street, Cambridge, U.K. CB2 1PZ	Fluid mechanics
Prof. R. Narisimha	Department of Engineering, University of Cambridge, Trumpington Street, Cambridge, U.K. CB2 1PZ	Fluid mechanics
Dr. P.A. Nelson	Institute of Sound and Vibration Research, Southampton University, Southampton, U.K. SO9 5NH	Control of aircraft propellor noise
Dr. I. Roebuck	Admiralty Research Establishment, Portland, Dorset, U.K. DT5 2JS	Complexity of control systems

Dr. C. Ross	Girton College, University of Cambridge, Huntingdon Road, Cambridge, U.K. CB3 OJG	Active sound control
Dr. J. Scheuren	Muller BBM BMBH, Robert-Koch-Str. 11, 8933 Planegg, Nr. Munich, FRG	Vibration control
Dr. Brian Schofield	British Aerospace Research Department, Civil Aircraft Division, Comet Way, Hatfield, Hertfordshire, U.K. A110 9TL	Aerodynamics
Dr. J. Sivasegaram	Dept. of Mechanical Engineering, Imperial College, Exhibition Road, London SW7 2AZ	Combustion
Dr. M.A. Swinbanks	8 Pentlands Court, Cambridge, U.K. CB4 1JN	Active sound control
Dr. D.M. Wells	Westland Helicopters, Yeovil, Somerset, U.K. BA20 2YB	Vibration control in helicopters
Prof. James Whitelaw	Department of Mechanical Engineering, Imperial College, Exhibition Road, London SW7 2AZ	Unsteady combustion
Prof.J.E. Ffowcs Williams	Engineering Department, Cambridge University, Trumpington Street, Cambridge, U.K. CB2 1PZ	Engine surge control

The Heard Island Acoustic Tomography Experiment

International Science Lecture Series

Inaugural Lecture

by Dr. James E. Andrews, ONREUR Scientific Director

Introduction

This lecture series, developed by the Office of Naval Research European Office (ONREUR), sponsored by the U.S. National Academy of Sciences and the U.S. Office of Naval Research (ONR), is international in scope, and will consist of lectures by several eminent U.S. scientists with a primary goal of increasing international scientific interchange. The inaugural lecture in Paris was cosponsored by the French Academie de Science and the Institut Francais de Researche pour l'Exploitation de la Mer (IFREMER). Dr. James E. Andrews, Scientific Director, ONREUR, introduced the lecture series. Dr. H. Lacombe, the Academie de Science and the University of Paris, introduced Dr. Munk, reviewing his multifaceted career and interdisciplinary approach to the study of the oceans.

While the Heard Island Acoustic Tomography Experiment provided the title and central topic of the Dr. Munk's presentation, the principal theme was the use of the acoustic experiment to validate (or invalidate) a global method of ocean temperature monitoring. While global climate change--global warming as a result of the accumulation of greenhouse gases in the atmosphere--is a topic of both scientific and political concern around the world, the evidence for the onset and rate of theprocess is widely debated. Prof. Munk discussed CO_2 records compiled from 1860 to the present that show an increase of 27 percent in this important greenhouse gas. Various investigators have computed that this increase should lead to an increase in surface temperatures of 1°C. The measured increase reported is in the range of 0.5°C, with the difference attributed to ocean heat storage. A major problem in this process is the modeling of ocean and atmosphere interaction. Nonetheless, the oceans play an important role in the balance of the global heat budget. Prof. Munk points out that the detection and demonstration of the greenhouse warming is far more difficult than the detection of the increase in CO_2. In fact, Prof. Munk indicated that the 0.5°C increase is of the same order as the errors introduced through changes in monitoring technologies over the period of the observations; e.g., switching from bucket measurements to engine intake measurements for sea surface temperature measurements and noting urban influences on meteorological stations. When the signal is of the same order as the error bars, it makes for global warming of the arguments as well. Prof. Munk made a special point that it is really the uncertainties of the models that make global observations important, and that it is such observations that will ultimately permit validation of the models.

The Heard Island Experiment was conceived by Prof. Munk to validate an acoustic thermometer approach to the measurement of the bulk ocean temperature. Stated most simply, the speed of sound increase 5 m/s per C, and sound fixing and ranging (SOFAR) channel experiments in 1960 showed that reception of acoustic energy was possible from relatively small sound sources along travel paths halfway around the world. Averaging by acoustic integration is then feasible over paths of ca. 15,000 km. For these distances, Prof. Munk pointed out that the effect of calculated global warming rates should give changes in travel time of 0.25 seconds per year. Acoustic tomography experiments carried out by Prof. Munk and others at ranges to 1,000 km have achieved precisions of 1 millisecond. And so the Heard Island Experiment was born.

Prof. Munk and his group selected Heard Island because it provides unimpeded geodesic paths to ocean areas off both the east and west coasts of North America (see Figure 1), allowing a global test. More importantly, in the southern latitudes the soundchannel rises towards the surface, and brings the axis within range of the depth capabilities of the sound source available for the experiment.

The experiment will be carried out from mid-January 1991, with transmissions over a 9-day period. The continuous wave (CW) sound source operates at a frequency of 57 Hz with an acoustic energy of 209 db. Transmissions will be 1 hour on, 2 hours off throughout the period. Scientists from eight nations are participating in the measurements, and will be monitoring the transmissions at sites from Antarctica to Bermuda, including Tasmania, New Zealand, California, Goa, India, the southern IndianOcean, and the North Atlantic.

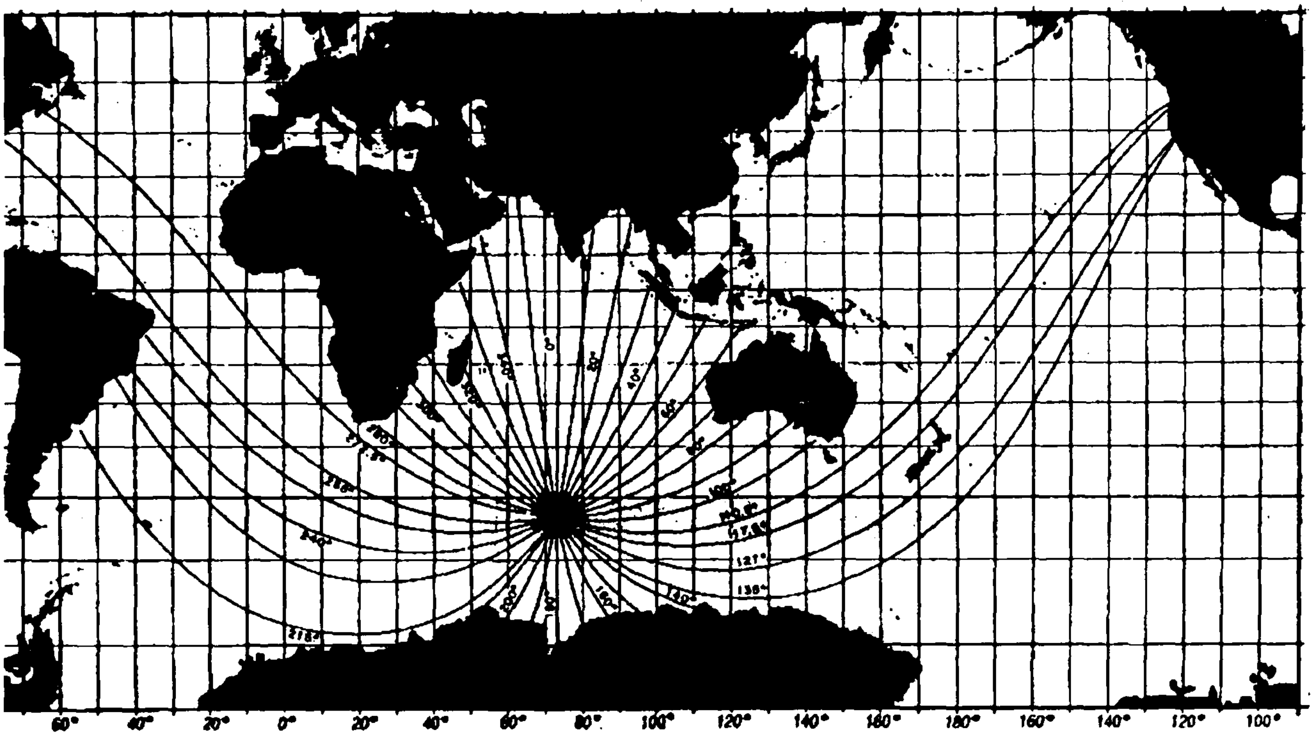

Figure 1. Heard Island Acoustic Tomography Experiment

Prof. Munk states that with a single source, all that can be done is to validate (or invalidate) the estimates of acoustic measurement ability based on model calculations. If validated, the implementation of an array of sources and receivers permits the application of tomographic inverse theory and leads to a mapping of ocean variability--including greenhouse warming. The central challenge will be to design an array that will optimize the probability of detection of the greenhouse trend against background variability--while remaining affordable. If done, the advantage is that it will extend the measurements of atmospheric work in the time domain to the space-time domain in the bulk ocean. As Prof. Munk points out, this would constitute a significant advance in our efforts to secure a timely and reliable warning.

Discussion

Following Prof. Munk's lecture, there was an active discussion of the questions raised and the issues surrounding global warming studies. The following is extracted from that discussion.

Questioner: You were presenting the propagation conditions in terms of vertical modes rather than rays. Could you comment on why you made this choice rather than talk about the rays?

Prof. Munk: Both views are valid but, as you know, the ray representation becomes increasingly inaccurate at longer ranges for a fixed frequency. We think it still has some reality at 57 Hz at 15,000 kilometers. But as you go farther and farther away for a given frequency, the ray arrivals become closer and closer together, and eventually become comparable to the period, and therefore the ray construction loses its reality. Whereas, for the modal representation, it's only a language. You can superimpose modes mathematically to give you the rays in a more general form and it might be the better way to look at the waves. So what Art Baggeroer has in mind with his vertical arrays is that he can filter mode frequency space and look, for example, at mode 3 at 52-53 Hz only, and then you could possibly look at the phase and phase changes. That may be the more robust construction for measuring travel time changes than hoping to find the constructive interference which we call rays. It's a sort of open subject. We don't know how we will come out.

Questioner: Do you expect some of the mode arrivals to be separable in the time domain?

Prof. Munk: Spiessberger has in fact suggested that you take your record and first split it up in the time domain and then look at it in the modal domain. It is conceivable that that is a good way to do it. I really don't know. But there is a possible combination of using early and late arrivals. The arrivals will probably last 20 seconds or so. So you take the first 5 seconds, the next 5, and the next 5, et cetera, and do separate analyses because they will have a different modal structure. One very interesting element of that, which I discussed recently at the Stewart symposium, and which I think has been totally overlooked by the acoustic community, is that different modes and different frequencies have different paths. It's like in light what is known as chromatic aberration. Different frequencies going through a lens are separated. So with our experiment, when you go through the Antarctic circumpolar current, the different modes will be refracted differently and will really see a different part of the ocean. So by making a modal decomposition and a frequency decomposition, you are looking along somewhat different paths. Now I don't know whether that is good or bad. If you could do it successfully, certainly it is good because it would mean that even for a single source/receiver pair, you would get more than one geodesic ray path. You are seeing different ones and you are getting more spacial resolution. It's bad..if it messes up the recognition in the analysis so much that you can't make any sense of it.

Questioner: I'm wondering what you are going to get because of the salinity variations in the ocean. We know that there are quite large ones and that they are persistent and some of them cover very large areas and that sort of thing is not really picked up by the Hamburg model (which Prof. Munk used to predict propagation). There is also another aspect that has been interesting me recently, and that is that with this Hamburg model. (And I don't know whether the one you are using does it or not.) It's able to produce a quasi-chaotic behavior in the ocean using this North Atlantic flip. That's possible, not actually going the whole way, but with very large variations in the bottom water formation. And if you vary the bottom water formation, of course you affect the temperature at depth over the whole ocean systematically. And I wonder if you would still get this reduction of noise by using your many paths.

Prof. Munk: First of all, the Hamburg model we used is the one that you described. It does contain salinities. In fact, salinities are the principal driver of the variability, and it has the result that has previously been described by Broecker and others--that the most important element of long-term variability is that somehow or another, the surface layers become light, low density, buoyant, and that prevents the formation of deep and bottom water. Now you can form a buoyant light upper layer two ways--by having it become warm, or by having it become fresh. Now if it becomes warm, it doesn't last very long because the heat will dissipate back into the atmosphere. But if it becomes fresh, you can't get the fresh water into the atmosphere so you have to wait until the salty water diffuses upward again. That is the largest variability of their model. It happens rarely, and it can lead to an absolute cessation of the formation of bottom water and it is the very model that we used. The salinity effect is second order. It's down by a factor of 10, which is not negligible. And one might hope to correct for some of it by some sort of an average T/S relation (one hopes). But your statement is certainly correct. Salinity is not measured by the speed of sound.

Questioner: Can this sort of measurement be combined with global inverse modeling of the temperature and salinity data and just use that as a constraint to get rid of that problem?

Prof. Munk: I think that is the way one should really do it. I can't conceive of any of these things in the future not going hand in hand with the modeling effort. The modeling effort will be a temperature/salinity effort and in some sense, the Hamburg model that we used did not compute temperatures. It computed sound speed using both the temperature and salinity. But what I think I said near the end of this talk was that in its most primitive form, this acoustic experiment is simply a validation or invalidation experiment. You compare the results with a given model and you find that it does or does not give you a sensible result. And that if you had a network of maybe five or six sources and two dozen receiving stations, you could begin to do mapping which is somewhat less model dependent and more on its own. Since I'm sort of an antimodeler--because I don't like it when I go to a meeting and hear people say if we could just get Terraflops of speed, we'll solve all oceanographic problems. It annoys me, and I have to hold my own and say there is still something to be said for making the measurements like this.

Questioner: There is a place where models could be useful because you've compared what you call natural variability effects to long-term trends. Now if there was a global warming or major changes in the ocean, it wouldn't effect just the average temperature but the position of fronts, or perhaps the statistics of eddies which are also effected which would affect travel time in a way that would be very difficult to recognize from a purely temperature effect.

Prof. Munk: Do you think the Hamburg model, that we used blindly, does allow that to some extent? It's a good model in some ways since it computed the sound speed along those paths. It didn't allow for the variability in the circulation, and people usually jump on us. But no one here has. We did assume that the ray paths themselves were unperturbed and computed the change in travel time from the change in sound speed along the unperturbed ray path. We may have to do a second order iteration and allow for the changed ocean and the changed ray path. This has been a subject that Carl Wunsch and I have really worked on for 10 years now and still don't quite understand. Except for the fact that the ray paths themselves were considered frozen, the Hamburg model gave us whatever variability it produces.

Questioner: I am quite curious about the large spacial variability in the Hamburg model which you showed as a sea-level patchiness essentially. How much of that horizontal variability is left in temperature at the sound channel? Is that a problem for you?

Prof. Munk: We could look back at the slide from the same model that showed the standard deviation of sound speed at the sound channel where I had these four panels, you remember. The third panel was in fact the outermost change in sound speed at the sound axis worldwide from the Hamburg model based on 3,000 years. Whereas, the picture we looked at on sea level was just the CO_2 effect--that was the signal. That was not the variability. The variability numbers that we used for the temperature variability at the sound axis (and it's very considerable) if you look at that, you will find that there are some places in the North Atlantic where the standard deviation is a number of times--three or four or five times bigger than it is in other parts of the ocean. And the suggestion that separation should be done in the space/time domain is based on just this consideration--that distribution of natural variability is spatially different from the distribution of the greenhouse signal, and one should take advantage of that in the analysis.

Questioner: Doesn't the same working model have these huge decadal variations in Antarctic circumpolar transport which would, as you say in the talk, kind of flip flop the warm and cold water circulation there which appears unrealistic in terms of the record of the last hundred years?

Prof. Munk: That's right. I wish the people were here who have done this thing. I think there are many objections to the model. My favorite sentence (and I'll say it once again, and thanks for giving me the chance) is: "The worse the model, the more the reason for us to go out and do some measurements." You agree with that?

Questioner: Could I, for a moment, turn the question around? One of the things that Walter and I had hoped to learn here was what was happening in the French oceanographic community in experiments or more model-oriented programs that relate to these kinds of global climate issues. We had hoped to have a panel that could address this. But because of illness, this has not come to pass. I was wondering if maybe I could ask a question of the audience. If there are complementary programs that are going on that might want to be trading secrets with Walter here a year or two down the road in terms of what each of you are learning about the world climate.

Prof. Munk: That would be very interesting. Do we have some comments? Of course, Yves Desaubies, working in Brest, has done work very similar to ours in connection with ocean acoustic tomography.

Yves Desaubies: But our work is not directly related to climate issues at the present time.

Questioner: Are there research programs within the French community examining such general ways of looking at the ocean with regard to the climate issue?

Prof. Munk: I have a feeling, Jim, that the idea is sufficiently mad and insane that the French community has not as yet followed it.

Questioner: But, of course, one should mention that the French and other European partners are heavily involved in the World Ocean Circulation Experiment (WOCE) experiment which will independently verify these trends by sea-going measurements.

Prof. Munk: We're in competition really with WOCE. I myself have the prejudice that these integrating measurements, by the very nature of spatially integrating, have some advantage over the collection of many spot measurements. But, of course, the whole ocean experiment is designed to tell you something about the fact of year-to-year variations.

Questioner: That's not what WOCE is for. There are very few repeat measurements in WOCE. However, there will be time series measurements.

Questioner: For instance, let's take one of the two ends of the scale--that Walter's experiment is wildly successful, that they are able to demonstrate that you can have this fine resolution in the acoustic travel times over these path lengths, and there is a strong argument for doing a longer term, say 10-year, observation. How would something like that relate to the structure of WOCE's measurement programs?

Questioner: I thought tomography was taken out of WOCE, basically.

Prof. Munk: We tried very hard to have tomography within WOCE, and obviously Carl Wunsch is at the very center of WOCE, so it wasn't a matter of not being known. But I think the community as a whole did not think the time was right to use acoustics in a major way to do oceanography. And some of us think it is--some of us younger people. There is a bit of a difference of opinion there. I would love to see it discussed more. Right here. It is a good topic.

Questioner: If I may make a comment, I think that the main impact of WOCE on the kind of thing that you're doing will be on the model. The main purpose of Core One of WOCE is to constrain the models. The modelers realize they don't have enough data. They would like to have your data as well as other kinds of data to constrain their model. And that is so we can get better models and are better able to interpret your kind of data.

Questioner: Talking about the implementation in WOCE, there are a bunch of process studies in the North

Atlantic which are a part of Core Three. Actually, this is all still pretty much in flux, and we had tried to get somebody from your group, or somewhere else, to come to this meeting and make a big stand for tomography And they said, "All these WOCE guys don't like our stuff." And nobody showed up. I had the feeling nobody wanted to put up a fight for it, and there's still space because it's in a basin-- a basin experiment in the North Atlantic which is perfectly the right scale which has been an improvement to reference tomography.

Prof. Munk: We consider you as being one of our closest friends and allies in this matter. But, of course, as you know I've been to many WOCE meetings where we discussed the possibility--one in Japan which we all went to together, and one in London. I think it is clear that the acoustic idea hasn't been accepted. Let me talk about tomography for a moment. Acoustic tomography has been going on for 12 years, and we have not revolutionized our understanding of the oceans in those 12 years. We spent much more time than we thought it would take to learn how to do the measurements properly. And now, at this time, there are two analyses underway--a triangle of 1,000 km on a side in the eastern Pacific, and the one year record off New England. Interesting results are coming out. I think our mistake was that the marketing group was too optimistic--assuming that things would happen so quickly. But that's my fault. And it's very natural, no matter what you take in, that the additional people will not accept it until thy have been shown that it works. And there has been some of that going on. And I guess that one's hope is that if we can show that it works well, it will become a more useful part of the oceanographic community.

Questioner: If your experiment works, wouldn't you go back to WOCE and try to implement more of that?

Prof. Munk: If they would welcome us with open arms, yes. But it probably is not a very important question. If it works, we really have to ask most of the people in this audience what would be appropriate. It would certainly have to be an international undertaking. Even this feasibility test now involves eight countries. Clearly, a 10-year global experiment would have to be done with very close international collaboration. And I don't know whether the WOCE program is the place. I don't know how to think about that. It hasn't come up.

Questioner: You mentioned several times that the sea level variations are a problem for long term measurements and monitoring. I don't want to be too much optimistic, as you mentioned, for tomography. But I think now we are starting a program for sea level in combination with altimeter, tidal gauges, and tracking stations constrained to tide gauges. We can expect 1-cm level accuracy on basin scale for 2 months next year with ERS-1, Topex/Poseiden, and we will have at least 50 tracking stations constrained on tide gauges. Maybe I am optimistic--and then we can have something to compare with.

Prof. Munk: I share your feelings on that. I think the combination of sea-level stations which are sort of vertical heat content integrators with the horizontal integration of the acoustics if proper actions are made for crustal movements, which hasn't yet been done successfully.

Questioner: No, No. I disagree. The tracking stations already existing are providing you the station position referred to the international earth reference system with an accuracy of 1 centimeter. We can claim that now.

Prof. Munk: Is that GPS (global positioning system)?

Questioner: Yes, GPS. And on the other hand, also DORIS. Now we have 38 stations around the world that are providing a few centimeters accuracy for your 5,000 kilometers, and they are by design linked very deeply to the tide gauge. And they are by design providing you the decollation between the crustal motions and the tide gauges all through it.

Questioner: I think this is very important (and I don't mean to denigrate it) but the fact is that since we are dealing with a signal in which is 2.7-mm per year is a very large signal. That's probably the upper limit of what we are getting. It's probably a little lower than that, and your 1 centimeter takes quite a few years before you get within that. And then there is the other problem that we aren't tackling yet and the upper changes in the geoid aren't fully negligible in this. There may be 30 percent of the other and that's a problem too. It's a very complicated problem.

Prof. Munk: There are significant changes in the geoid?

Questioner: Yes. You get mantle movements probably still associated with the relaxation after the glaciation and that kind of thing. It's not negligible.

Questioner: If you can't get the 18,000-kilometer path length, how long a path length are you going to need in order to look at the global warming problem? Can you do it with 5- and 6,000-meter paths and repeaters?

Prof. Munk: Yes. I think now we are still learning about it and that what you want is a gyre resolution because its some ways from the little we have seen--the slides I showed you--the warming is not uniform. If you said what are the scales of storm warming, low warming, cooling, and the sea level data is from a gyre scale, there sort of unique gyres for the world's oceans-- the subtropic subpolar gyres north and southern oceans. You want to resolve those that you want to smear over the mesoscale, and I think that means something like 10,000-kilometer kind of scales, and maybe one should try and think of how to design a system that is ideal from the point of view of resolving different gyres and yet having the integrating power for smearing the necessary mesoscale out. Does that make sense, Tom? It hasn't been really carefully thought about.

Questioner: But you can do that from a spatial array in the middle of the Pacific rather than a linear array across the Pacific, using an average faster xy.

Prof. Munk: Maybe it is true that you would be better off in less than the antipodal transmission. Don't forget. We were limited to this experiment to a high latitude source because of the depth limitations of the source. If we go to the next phase and build special sources for the global warming thing, we will not have that depth limitation, and we might be better off with a less demanding location for the source. I think that is something that people really need to work on trying different configurations, finding out how they work, using models to see, and that attempt that I mentioned to you that lead me to the 10-year number was, I think, the zero order attempt to get some feelings on how that should be handled.

Questioner: I was wondering, with long range acoustic propagation under sea ice to measure ice thickness--how can you do that?

Prof. Munk: In the Arctic, you know, acoustic rays are called RSRs (refracted-surface-reflected). They look like this. They go deep and come to the surface. We have just had six moorings in the Greenland seas for 1 year and they were all frozen over twice during the winter and have all been recovered. While they are frozen over, you have reflections from the bottom of the ice and refractions from the water below and you can use that kind of data, it is thought. It has not been done really to measure the mean thickness of the ice. You will find some work being done at this time on this subject by Jim Lynch at Woods Hole, and I believe you will find that that's possible. You know that there has been a claim on the basis of two submarine passages under the Arctic that were 20 years apart that here is a significant difference in ice thickness. But I think most of us don't like to take two points that are 20 years apart and draw a straight line through that. So one would like to take a 10-year time series. The thickness of the ice cover does affect the travel time. I believe though it has not been published--demonstrated--that it should be possible from the time series of this sort to learn something about the ice thickness.

Questioner: I'd like to make one final comment about a conversation that Walter and I had recently, and that I find interesting with regard to the discussion here because my background is in the marine geology and marine geophysics area. The same kind of dissention exists between geophysicists and acousticians as between the oceanographers and acousticians. And forums like this I find very fascinating because of the interaction of the two groups and the opportunity to maybe encourage interdisciplinary trading of ideas and/or competition so that yours comes out best in the end. And so we hope in both domains the groups continue to collaborate more closely.

Prof. Munk: May I make a comment on that because I really regard myself as a physical oceanographer? I came to acoustic interests very late in life--12 years ago--and some of my best friends are oceanographers. The thing that has been interesting in going to this new field of acoustics is that it is heavily dominated by signal processing. It is very odd that is the sort of field that was all by itself and paid very little attention to the true medium of the ocean. It was like people who go to Harvard Business School and consider themselves to then be competent to run any industry possible--as qualified to run General Motors as to run a house of prostitution--having all the necessary means of doing that. And the same is true of signal processors. We have signal processors who can do anything. The real progress in the last 10 years in ocean signal processing, which has been enormous, has been almost entirely due to signal processors deciding that in the methods that they use that they should know something about the ocean.

Summary

The U.S. National Academy of Sciences will publish the full text of Prof. Munk's lecture. Prof. Munk hopes to present early results of the acoustic analyses in mid to late 1991. The Heard Island Acoustic Tomography Experiment is supported in the U.S. by the Office of Naval Research, the Department of Energy, the National Ocean and Atmospheric Administration, and the National Science Foundation. The generous assistance of the science staff of the U.S. Embassies in Paris, Delhi, and Jakarta has been an integral part of the success of the inaugural lecture.

A Symposium on the Dynamics of Marine Vehicles and Structures in Waves

by David Feit

Introduction

The International Union of Theoretical and Applied Mechanics (IUTAM) sponsored a Symposium on the Dynamics of Marine Vehicles and Structures in Waves at Brunel University, Uxbridge, England. The meeting took place on May 25-27, 1990, and preceded the Royal Society Discussion Meeting on the Dynamics of Ships. Many of the same people attended the latter meeting.

Professor W.G. Price and the late Professor R.E.D. Bishop planned and organized the meetings (the meetings were dedicated to Bishop). After Bishop's death, Price and Dr. P. Temarel carried out the original plans. These efforts resulted in an excellent and informative series of papers, discussions, and social events shared by all participants and accompanying members. More than 100 attendees from 24 countries participated in the Brunel symposium.

A meeting about the same subject, organized by Bishop and Price, was held at University College, London (UCL), in 1974. At that time, the organizers were affiliated with the Department of Mechanical Engineering at UCL. Later, both Bishop and Price moved to the Brunel University. Bishop, as UCL's Vice-Chancellor, and Price, as Professor of Applied Mechanics, directed a very intensive research program in maritime engineering (see ESNIB 89-05:1-2). During the current meeting, Professor Price announced that he would become Professor of Ship Science at the University of Southampton. He will succeed Professor G.J. Goodrich who is retiring.

I attended 2 days of the meeting, and I will discuss several presentations. Although this field is not within my current specialization area, I felt a sense of *deja vu* during the presentations. During the earliest stages of my career, while still a graduate student, I worked in ship hydrodynamics. F. Ursell, a leading figure in the field, presented the first talk, and I remembered his name from reading the hydrodynamics literature.

Mathematical Contributions to Waves and Ships

Leading mathematicians have long favored ship hydrodynamics as a field in which their skills can be fruitfully applied. F. Ursell, Department of Mathematics, Manchester University, U.K., is one of these individuals. His invited lecture reviewed original contributions he has made to the theory of water waves. The first problem he encountered was forecasting waves on beaches in preparation for troop landings in the Pacific. These waves were not local waves, but waves that might have traveled hundreds or thousands of miles, being generated by storm winds far out at sea. Using results first discovered by Cauchy and Poisson on the travel time of surface waves (Lamb, 1932), Ursell was able to deduce the time of the generating disturbance and the location of its genesis. Modern wave forecasting methods are all based on these principles.

Ursell was also responsible for the methods of calculating the hydrodynamic wave forces acting on a half-immersed cylinder as a function of the ships heaving and rolling frequencies. These results are fundamentally important in ship design.

The final problem that Ursell discussed was his contributions to our understanding of Kelvin ship-wave patterns and wave resistance. He showed (Ursell, 1960) what the ship wave pattern is near the critical angle $_c$. To do this, he developed a single uniform asymptotic expansion valid in the region where two stationary phase points become nearly coincident.

During the meeting, I learned that Professor Ursell will soon retire from his position at Manchester University. We hope that in his retirement he will continue to contribute to our understanding of ship hydrodynamics.

Waves in a Basin

Professor C.C. Mei, Massachusetts Institute of Technology, Cambridge, presented a paper on the "Short-Wave Excitation of Long Waves in a Basin." The nonlinearity of surface waves induce second order waves with sum and difference frequencies. If the first order, short waves have a narrow frequency spectrum, the different frequencies that arise can force slow drift motions of a ship or submersible. Also, if the wave train is incident on a closed basin such as a harbor, resonant oscillations of the water waves can occur with their dangerous side effects. Mei presented some new theories for predicting and controlling these phenomena. During the discussion period, W.C. Webster raised a question about the source of low-frequency excitation given the presumed narrow band nature of the incoming wave train.

It was not clear that he was completely satisfied with Mei's response. The matter was probably clarified in the very valuable hallway discussions that inevitably take place at such meetings.

The Behavior of Ships in Waves

R.F. Beck, University of Michigan, Ann Arbor, presented a paper that he coauthored with A.R. Magee on time domain analysis of ship motion in waves. In this approach, the hydrodynamic problem is solved directly in the time domain as an initial value problem. This is contrasted with the more usual frequency domain approach. In the linear case, the two approaches are related by Fourier Transforms. However, for fully nonlinear simulations, Beck argues that the time domain approach is preferred. Also in finite forward speed, the calculation of the frequency domain, Green's function becomes extremely cumbersome and the time-domain approach is significantly faster. In comparisons with experiments and strip theory, he stated that time-domain analysis gives mixed results. The primary motivation is for nonlinear analysis where the body boundary conditions are satisfied on the actual instantaneous wetted surface, and research towards this application continues at the University of Michigan.

H.H. Chun and R.C. McGregor, Department of Mechanical Engineering, University of Glasgow, Scotland, submitted a paper on "First and Second Order Wave Effects on SWATH Ships in Waves." McGregor made the presentation. On certain SWATH models, there have been experimental findings that indicate a dramatic decrease in their wave resistance over a speed range in the super-critical zone. The reported investigation was a theoretical attempt to clarify this result. They looked at first- and second-order wave effects using a three-dimensional (3-D) panel source distribution technique and compared these results to model test data. Unfortunately, the present theory does not yet provide the final explanation for the negative added resistance situation. The authors recommend, however, that the interference between the steady and unsteady potential be more fully considered.

On a much more practical vein, the next talk, based on a paper written by N.G. Pegg, L.E. Gilroy, and D.W. Cumming of the Defense Research Establishment, Nova Scotia, Canada, discussed the results of sea trials performed on a 75-ton SWATH vessel, the Frederick G. Creed. The trials took place in winter seas off the coast of Nova Scotia in the North Atlantic. Measurements were made with pressure transducers located in the haunch, box, outer topsides, and antislamming strakes. Also, two dozen strain gauges were mounted in the primary transverse bulkheads. The presentation ended with a video showing side-by-side motion trials conducted with a much larger monohull. The SWATH ship showed much better sea-keeping characteristics than the monohull. An active control system kept roll and pitch motions to a minimum. However, the SWATH ship experienced some degradation of personnel and equipment performance which did not occur on the monohull. This is thought to be caused by excessively large heave and sway acceleration levels in the high-frequency range. The results presented were preliminary, and in the future, the authors hope to correlate the motion, structural response, and pressure loading with sea state, speed, and heading.

Computational Approaches

Two other papers presented during the first day dealt with fairly novel computational approaches to fluid flow problems. I did not hear either of them, but on looking through the written versions, they appear to be quite interesting and worthy of further study.

The first by W.C. Webster and J.J. Shields, University of California, Berkeley, is entitled "Applications of High Level Green-Naghdi Theory to Fluid Flow Problems." From a quick reading, I learned that Green-Naghdi theory is an approximation scheme in which 3-D field equations are transformed into two-dimensional equations by prescribing the kinematic variation of the dependent quantities along one coordinate direction. The complexity of the kinematic variation assumed presumably allows for increasing accuracy of approximation. The resulting equations are more easily solved numerically than the original 3-D equations. The applications discussed in the paper are to time-domain, shallow- and deep-water applications. The necessary equations are constructed using symbolic processing languages and then only modest computing facilities are required for their numerical calculation. I recommend this paper as an excellent and very readable introduction to the approach.

The paper by W.G. Price and Ming Yi Tan, Brunel University, on "The Evaluation of Steady Fluid Forces on Single and Multiple Bodies in Low Speed Flows Using Viscous Boundary Elements," derives an integral equation formulation of the problem. The resulting nonlinear integral equation requires a body distribution of singular solutions, called "Oseenlets" (solutions to a modified Oseen equation) through the fluid domain while the linearized problem needs only a body surface distribution. The method is most appropriate for calculating the steady fluid forces acting on closely spaced bodies place in a uniform low-speed viscous flow.

Hydroelastic Response of Marine Structures

The second day of the meeting began with three talks on the hydroelastic response of marine structures, all of which were contributed by Far Eastern participants.

S. Miao, Dalian Institute of Technology, People's Republic of China, discussed the coupled bending and twisting vibrations of beam-like structures. The work presented was initiated and completed while the author studied at Brunel University. He investigates the solutions of uniform nonsymmetric beam vibrations as applied to ship hulls. In particular, he develops proportional relationships between various internal actions. These are most applicable near the extremities of the hull. An example of such a relationship is that the ratio of the horizontal bending moment and shear force is proportional to distance from bow or stern for all time, independent of the type of excitation. Such a relationship becomes less accurate with increasing distance, but are more generally valid for open and closed beam sections. Such concepts are useful to designers of container and SWATH ships.

The next paper by T. Fukasawa, University of Tokyo, considered the hydroelastic response of membrane structures in water. Hydroelasticity regards ship motion as rigid body motion plus that induced by the hydrodynamic forces interacting with the elasticity of the structure. For applications to ships, the problem is formulated in the book by Bishop and Price (Bishop, 1979). In this paper, the author calculated the dynamic response of a membrane structure radiating caused by motion and responding to waves. He finds that the added mass and damping in radiation show abrupt changes at the eigenfrequency of the fluid-loaded membrane. The added mass becomes negative (stiffness-like). However, at frequencies below the eigenfrequency, the damping is increased over that caused by rigid body motions and eventually decreases to zero. For the wave diffraction problem, he concludes that the transmission coefficient tends toward zero, and the reflection coefficient approaches unity at a frequency corresponding to an interference between the membrane-radiating waves and the rigid body-scattered waves. As a result of his calculations, he believes that the heaving motions of a vibrating structure can be controlled by using a pressurized membrane whose resonant characteristics are adjusted by the internal pressure. Similar control of reflection and transmission of sea waves can be achieved using the same principles.

The final paper in this area dealt with engineering approaches to hydroelastic analyses of slender ships. This paper was written by Y.Wu, J. Xia, and S. Du, China Ship Scientific Research Center, Wuxi, China. In this paper, Newman's unified slender body theory (Newman, 1978) is extended to admit the elastic beam modes of slender bodies. This allows for the development of a theory accounting for the hydrodynamic interaction along the length of the vibrating ship. A dynamic mode refinement approach, whereby the details of the displacements and stresses in a prescribed substructure can be determined without resorting to a full finite-element analysis of the entire structure, is presented. If this approach proves to be acceptable, it will provide a valuable tool for predicting the reliability, safety, and behavior of slender ships.

Nonlinear Motions of Ships on the Sea Surface

The last series that I will discuss is a group of three papers that investigate the motions of ships when they are forced into the nonlinear range of motion.

A. Francescutto, University of Trieste, Italy, discussed the nonlinear motions of ships and structures in narrow band seas. This paper reviews and discusses the relevance of new concepts coming out of nonlinear dynamic analysis. Examples are bifurcations, amplitude jumps, symmetry breaking, deterministic chaos. According to the author, these notions are now circulating among a limited group of researchers in dynamics. His main purpose appears to be introducing these concepts to the naval architects, several of whom may look upon nonlinear dynamics with some trepidation. Although I am not a naval architect, his paper was extremely enlightening as an introductory exposition of nonlinear dynamics applied to ship dynamics. Although at times, his style of writing is somewhat awkward, I would eagerly recommend reading this paper to anyone interested in applications to naval architecture.

S. Kisliakov, Higher Institute of Architecture and Civil Engineering, Sofia, Bulgaria, spoke on nonlinear oscillations and chaos related to a single degree of freedom (sdof) system excited by a regular wave packet. The author performed this work while he was a Humboldt Fellow at the University of Wuppertal, the Federal Republic of Germany. He studied the forced and parametrically excited vibrations of a damped, nonlinear sdof oscillator exposed to a sequence of Dirac delta impulses. His approach uses Melnikov's Method (Lichtenberg, 1984) which establishes the conditions for chaos in a dynamic system. He concludes, however, that further research is required to determine the true applicability of Melnikov's Method to such problems.

J.M.T. Thompson, UCL, presented the final paper related to nonlinear dynamics. He spoke on "Transient Basins: a New Tool for Designing Ships Against Capsize." In this paper, he models the problem of a boat capsizing as a damped nonlinear oscillator excited by a short train of regular waves. The problem can then be viewed as escape in finite time from a potential well under periodic forcing where the rolling motion is the time-dependent parameter. The procedure he recommends is to solve the nonlinear equations numerically using the phase space concepts of geometrical dynamics (Thompson, 1989). He showed several examples in which he calculates the phase space trajectories from a starting grid, and gradually increases the amplitude of the forcing function. The results show sudden erosion of the safe basin at a critical value of the forcing. This critical value can be obtained by a relatively small number of short time integrations of the equations yielding a useful index related to the capsizability of the design.

Concluding Remarks

This meeting was a prelude to the Royal Society Discussion Meeting on the Dynamics of Ships (see this issue, page 30, "Royal Society Discusses the Dynamics of Ships") and brought together many of the top scientists in marine hydrodynamics. Although many of the contributors were from the U.S., an even greater number were European and from the Far East. Major developments in the field were presented and discussed, such as time domain analysis, vibroelastic response of marine structures, validation and verification of large-scale computational schemes, and the application of recent advances in nonlinear dynamics to ship motions. This meeting and the Royal Society Meeting are enduring tributes to Professor Bishop who contributed so much to the planning of the meeting and generally to the field of ship dynamics.

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Royal Society Discusses the Dynamics of Ships

by David Feit

Introduction

On June 28-29, 1990, the Royal Society held a 2-day discussion meeting on the Dynamics of Ships. The meeting was held at the Society's headquarters at 6 Carleton House Terrace, London. More than 125 people attended, many of whom had also participated in the International Union of Theoretical and Applied Mechanics (IUTAM) Symposium on the Dynamics of Marine Vehicles and Structures in Waves (see this issue, page 26, "A Symposium on the Dynamics of Marine Vehicles and Structures in Waves"), held just before this meeting. The meeting was divided into two parts. The first day was devoted to discussions related to rigid ships, while during the second day, flexible ships were considered.

W.G. Price gave the opening talk. Price and the late Professor R.E.D. Bishop had organized this meeting. Price was associated with Bishop for 20 years both at University College London and more recently Brunel University, Uxbridge, U.K. He dedicated the meeting as a memorial symposium to Bishop, and asked the audience to stand for a moment of silence in tribute to Bishop. I will briefly discuss some of the papers presented.

Background and Motivation for the Meeting

The opening talk was entitled "Some Comments on Present Day Ship Dynamics," authored by both Price and Bishop. Price stated that, although ship dynamics is very clearly not a new subject, it is by no means a subject that should be considered closed. Reports of casualties at sea continually make us aware of this. He reported that in the last 10 years, there have been 180 ships lost at sea with the concomitant large losses of life and goods, and sometimes disastrous effects on the environment. Ironically, on the day the meeting held its banquet at Lloyds of London, we learned about a maritime casualty off the coast of Japan. Because of such occurrences, there still appear to be serious questions to ask and consider regarding maritime safety. Using this as background, Price set the scene for the ensuing discussions among the international gathering of maritime engineers and scientists.

Scale Model Experiments

Professor J. Gerritsma, Ship Hydromechanics Laboratory, Delft University of Technology, the Netherlands, talked about forced oscillation experiments. In these experiments, ship models are forced sinusoidally in specific modes of rigid body motion and the in-phase and quadrature components of force caused by the reactive loading of the water are measured. The in-phase force component represents the added mass, while the quadrature component measures the damping. In 1946, Khaskind performed the first experiments of this kind in the U.S.S.R. He showed comparisons of test results with early theoretical ones developed using two-dimensional (2-D) strip theory. Comparisons were also shown with calculations obtained using panel methods and the WAMIT (developed at Massachusetts Institute of Technology [MIT], Cambridge, by N. Newman and P. Sclavounos) program. This paper attracted a good deal of attention, principally, I believe, from those involved in theoretical modeling. They pointed out that comparisons between theory and experiments would be better if results using more modern computer resources had been utilized in the comparison.

Current Prospects for Three-Dimensional Theories of Ship-Wave Interaction

J.N. Newman, MIT, gave a review paper on the three-dimensional (3-D) theory of ship-wave interaction. First, he discussed the interaction of water waves with marine vessels in terms of classical potential theory. In the linearized theory, strong numerical schemes exist only in those cases where zero forward motion is assumed or the body oscillates about a fixed mean position. There are no satisfactory engineering tools for calculating the wave forces for ships moving through a seaway. He mentioned that because of the disparity of two separate length scales, and two differing wave speeds, the problem is extremely difficult. Because of the disparity of the length scales, strip theory has been modified incorporating results from slender body theory. Still, the results are not completely satisfactory. He is optimistic about the use of computational techniques applied to the full 3-D equations. Also, he showed some graphical results of ship waves calculated on the basis of such a theory.

Wind Loading of Ships

J.A.B. Wills, BMT Fluid Mechanics Ltd., Teddington, U.K., presented the results of recent studies on the wind loading of ships. Wind loading is of critical importance in rolling stability. In the simplest approach, wind loading is represented as a constant rolling moment that adds to the wave loading. For a more advanced model, the wind is taken as sharp-edged gust that is usually applied at the critical point in the vessel's roll cycle. Then, the ship's motion is calculated. Statistical approaches can also be applied by assuming a real or simulated wind-time history acting on a dynamical model of the vessel. The statistics of the response are then calculated after numerical solutions are obtained. The talk ended with a video showing small model tests in a laboratory-simulated wind and wave environment. This particular paper generated more than the usual amount of discussion. The principal question concerned the scaling of the model shown in the video with respect to the wind loading, since the same geometrical scaling was used for the submerged portion as well as the above-water structure. An individual from the British Department of Transportation questioned the scaling of the freeboard and the drainage ports for the water that accumulates on the decks. According to the author, the drainage area was scaled but there was no attention given to the detailed geometry of the drainage ports.

Seaway-Induced Ship Bending and Shear Stresses

P.C. Temarel, Brunel University, began the discussions related to flexible ships. He presented formulas for the estimation of bending and shear stresses in beam-like ships travelling in a seaway. Hydroelastic studies of beam-like structures have been underway for the last 15 years. Experimental observations going back to 1984 have shown the proportionality between bending moment and shear force in certain areas of the hull for certain types of hull motion and distortions. This paper examines the conditions under which this proportionality holds. More importantly, it discusses the implications of such findings to the naval architectural designer. This is especially important with respect to the bulk carriers, some of which are now approaching 15-20 years of at-sea service.

Numerical Towing Tank

H. Maeda discussed model techniques and prospects, and this talk seemed to raise some eyebrows. Essentially, the talk introduced the specter of a "numerical towing tank" and the potential redundancy of existing towing tanks. Professor Maeda did, however, concede that special physical experiments would be necessary to validate the fundamental assumptions and descriptions of the physical mechanisms. These types of experiments would not, he contends, need the facilities of the large model basins already built or those still in the planning stage. Statements of this type, if not carefully interpreted, can sometimes be used by legislators or oversight committees to thwart plans or projects, especially in an era of budget restrictions. Several people disagreed rather strongly with some of the notions expressed by this author.

Concluding Remarks

The proceedings of this meeting, including the papers and written discussion, will be published in two different formats--as part of the Royal Society Proceedings and as a separate bound volume. This meeting, like the IUTAM meeting at Brunel, brought together most of the world's leading experts in ship hydrodynamics to discuss progress in the field. Many are European, and an unusually large number appear to be from the Far East. I understand that world-wide maritime production is drastically reduced now, but the concentration of shipbuilding has moved from Europe to the Far East. In conversation with one of the leading U.S. scientists, he mentioned that contrary to the previous meeting of this type held in London in 1974, he noted there were fewer U.S. scientists at the current meetings. I have found this to be true in general over the last 2 years, and have generally attributed this to travel budget limitations rather than lack of U.S. interest in European scientific endeavors. Quite to the contrary, it appears to me that the pursuit of mechanics-related research in Europe is much more vigorous than in the U.S. Therefore, it is to America's benefit to maintain close liaison with European research efforts.

Natural Sources of Underwater Noise in the Ocean

by David Feit and LCDR Larry Jendro USN Dr. Feit is the Liaison Scientist for Acoustics and Mechanics in Europe and the Middle East for the Office of Naval Research European Office. LCDR Jendro USN is the Liaison Officer for Oceanography and Environmental Systems at the Office of Naval Research European Office. LCDR Jendro is an active duty naval officer from the U.S. Navy's oceanography community.

Introduction

Now is an exciting time to be doing research on ambient noise sources in the ocean. The 1987 Lerici Conference, Natural Mechanisms of Surface Generated Noise in the Ocean, not only gave impetus to research efforts but also provided focus resulting in the stimulation of well-directed research. Now, 3 years later, the conference entitled Natural Sources of Ambient Noise in the Ocean, held at Downing College, University of Cambridge, U.K., provided the forum for the exposition of much of that research effort. Significant advances in most established areas were reported and some very interesting new ideas were put forward.

The conference was well organized by Dr. Bryan Kerman, Department of Applied and Theoretical Physics, University of Cambridge. Invited papers were featured by: W. Carey, I. Dyer, J. Ffowcs Williams, K. Melville, M. Longuet-Higgins, J. Orcutt, and P. Thorne. Forty additional papers were given and 11 posters were displayed during the conference. The papers were generally grouped into four interest areas with research efforts in the same interest area presented together. This organization emphasized similar and disparate methods and results, and facilitated discussions. General areas were:

- Surface Wave-Generated Noise
- Low-Frequency Surface Generated Noise
- Rain Noise
- Noise in the Arctic.

Generation of Noise at the Ocean's Surface

J. Ffowcs Williams, Department of Engineering, University of Cambridge, set the stage by reviewing the processes of sound creation emphasizing the generation of sound near the air-water ocean surface. The phase speeds of most surface waves are subsonic along the ocean-air interface and therefore do not radiate sound into the ocean depths unless they encounter some spatial inhomogeneity such as a scatterer. One must therefore consider other sources of sound. He concluded that the principal sources are momentum density changes near a free surface. He differentiated between the wave center of the scattered field and the energetic source of that field. He pointed out that the nonuniqueness of the source process allows the development of an acoustic analogy adapted for unsteady inhomogeneous flows. He emphasized source processes involving air bubbles close to the free surface. Their interaction with the free surface implies characteristic properties of the sound they scatter. Source properties of a very rough sea were modeled through an acoustic analogy incorporating free surface effects. Also, estimates were made on the frequency ranges provided by particular source processes.

Y.P. Guo, a former student of Ffowcs Williams and now a research associate at the Massachusetts Institute of Technology (M.I.T.), Cambridge, discussed bubble pulsations excited by non-linear surface mode interactions as a near surface sound mechanism. This paper compared two components of bubble pulsation noise. One component, in a theory propounded by Guo and Ffowcs Williams, is because of the first order internal resonance. The other at the second order, discussed by Longuet-Higgins, results from non-resonant surface modes. Although the two components occur at different orders, they can have comparable amplitudes. However, Guo concluded that the second-order component is not significant because it showed a very irregular noise spectrum with most of its energetic modes well below the bubble resonance frequency. At such frequencies, energy is dissipated by thermal conductivity effects, while the first-order pulsation is at the bubble breathing mode frequency at which dissipation is minimum. The lively discussion on this paper gave one the distinct impression that there exists a lot of disagreement between the theories of Longuet-Higgins and that of Guo and Ffowcs Williams.

E.C. Monahan, Marine Science Institute, University of Connecticut, Groton, presented a particularly interesting descriptive paper, Occurrence and Evolution of Acoustically Relevant Sub-Surface Bubble Clouds and their Associated Remotely Monitorable Surface Whitecaps. His results included a model for the evolution of a bubble cloud from birth until disappearance into diffuse background bubble population. He illustrated this model in a sketch describing the various stages of the evolution of bubble plumes and their associated whitecaps.

P.A. Crowther, Marconi Underwater Systems Ltd., Waterlooville, Hampshire, U.K., followed with animation for this illustration by describing an experiment that was conducted off the Scilly Isles in the U.K. He placed a receiver at 80-m depth, 3 miles offshore, listening to frequencies between 6 and 100 kHz and produced a time series of sea noise at 10 kHz intervals. Analysis of the time series showed that the majority of surface noise comes from localized events. By analyzing auto correlation, Crowther could link the noise sources to surface waves, and track noise sources at one-half wind speed in the direction of the wind. This relationship of surface noise to waves was verified by the optical sighting of breaking waves 9 out of 10 times in relation to the strongest noise signals. Crowther said, "Sources of noise at the surface of the sea are localized spatially. The speed and lifetime of these noise sources can be related to wind speed. Breaking waves can be identified as noise sources."

M.S. Longuet-Higgins, Center for Studies of Non-linear Dynamics, La Jolla Institute, California, reviewed the mechanisms of bubble-generated noise. He talked about bubble noise in the 1-80-kHz range. First, he described the process of formation of bubbles by surface waves. He emphasized the role of the rapid development of steep slopes and entrapment of air by capillary waves and the formation of 50- to 100-cm bubbles in spilling surface waves. He described the nature of bubble resonance noise as pulses of single frequency, exponentially damped. He described vibration mechanisms as breathing mode and shape oscillations. He stressed the role of resonance emphasizing the exchange of energy between different normal modes. Evidence of the importance of this process was taken from many experiments. Longuet-Higgins also discussed the production of sound by rain drops. He referred to an analytical model that demonstrated the dominant role of the initial velocity of inward fluid velocity at the instance of bubble closure when compared to the mechanisms of bubble closure or shape oscillation.

Low-Frequency, Surface-Generated Noise

William Carey, Naval Underwater Systems Center, New London, Connecticut, presented a paper entitled Low-Frequency Noise from Breaking Waves. He stated that the dynamic evolution of plumes and clouds caused by the breaking of waves is a mechanism for the production of sound at lower frequencies between 30 and 500 Hz. Carey separates this sound source from that arising before the formation of a breaking wave. This suggests that the mechanism of sound generation from the prebreaking wave is the interaction of surface waves with the turbulence in the near surface layer. Also, this compares this low-level local noise to the thermal noise floor at higher frequencies. In describing the environment encompassing the bubble clouds as "regions of low sonic velocity due to their appreciable void fractions," Carey defines regions that must behave as compressible regions described by sonic speed and density. In the presence of a pressure relief surface, these result in effective dipole radiators which, when driven by wave breaking vorticity and turbulence, can result in levels of sound comparable to that observed.

Carey's description of bubble cloud regions as having appreciable void fractions was verified by laboratory experiments reported on by W.K. Melville, Department of Civil Engineering, M.I.T., in Bubbles, Noise and Breaking Waves: A Review of Laboratory Experiments. Melville used bulk conductivity measurements to determine that "...void fractions of 10 percent may persist for the order of a wave period following breaking. These values are many orders of magnitude greater than the average values in the upper few meters of ocean...." Of potential operational Navy interest was the correlation Melville found between the sound generated by breaking waves and the microwave scattering they produce.

In Observations and Causes of Ocean and Seafloor Noise at Ultra-Low and Very-Low Frequencies, John Orcutt, Institute of Geophysics and Planetary Physics, Scripps Institution of Oceanography, San Diego, California, summarized the currently accepted sources of noise in the frequency range of 1 mHz-50 Hz:

- 1-3 to 50 Hz - Shipping noise and breaking waves
- 100 mHz to 1-3 Hz - Microseism band, interactions between surface wave trains
- 20 to 120 mHz - "Noise Notch" currents and turbulence on the sea floor boundary layer
- mHz - Nonlinear coupling between groups of wind waves or free gravity waves that are independent of overhead swell and wind waves.

Noise from Sea Ice

Sea ice in the polar regions is an important natural physical source of noise and 11 presentations involved ice as a noise source. Ira Dyer, Department of Ocean Engineering, M.I.T., reviewed the mechanisms for generation of noise with his presentation, Source Mechanisms for Arctic Ocean Noise. He analyzed 10,000 recorded noise transients in the frequency range between 10 and 2,000 Hz and found similarities in the sequence of frequencies emitted. He then related this sequence of an initial high-frequency event (100-2,000 Hz) followed by a lower-frequency (5-100 Hz) event to the physical processes involved in ice fracture. The high-frequency emission is related to the actual fracture of the ice. The following lower frequency is emitted during the return of the ice to predeformation loading. He found these two processes to be further distinguished by radiative characteristics, the fracture motion having octopole characteristics and the unloading motion having a dipole characteristic. Dyer found the stress conditions in ice to be more appropriate to rheological than elastic properties. An interesting comparison was drawn between the similar problems involved with modeling the behavior of sea ice. This is based on laboratory ice experiments and in earthquake science, trying to model real rock with laboratory rock materials.

John Lewis, Science applications International Corp., Long Beach, Mississippi, in Aspects of the Mechanics and Modelling of Thermally Induced Stresses in Arctic Pack Ice as Related to Under-Ice Ambient Noise, also addressed this rheological nature of ice in response to stress. When discussing the overall problem of thermal stress in sea ice he said, "This involves the vertical structure of thermal conductivity and specific heat as well as a rheological model relating stress to strain." He compared numerical model stress variations with concurrent under-ice noise variations and found that "thermal heating can often produce fracturing of the interior of a floe, accounting for some anomalous noise spikes in higher frequency noise records after the passage of atmospheric warm fronts. Also, the sporadic nature of under-ice noise during a cooling night is related to the non-linear, rheological characteristics of sea ice."

In a separate presentation, Relating Under-Ice Noise to Thermal and Motion Induced-Ice Stresses in the Arctic Ocean, Lewis compared under-ice acoustic noise with calculated thermal and motion-induced stress. He found good correlation between high- frequency noise (>500 Hz) and thermal stress and between lower-frequency noise (<500 Hz) and motion-induced noise. His observations also showed that the maxima of motion-induced stresses are considerably less than thermally induced stresses sometimes by an order of magnitude.

In The Influence of Ice-Edge Eddies on Ambient Noise Under Various Environmental Conditions, H. Sagan, Nansen Remote Sensing Center, Bergen, Norway, investigated suspicions that the marginal ice zone may have ambient noise "hot spots" related to ice edge eddies. She found slightly noisier areas in the eddies at the edge with increases in high-frequency (315-1,000 Hz) noise associated with the center of the eddy, caused by convergence of ice. Other factors, the depth of water and whether or not swell was present, had significant influence on the findings. In one case where swell was present, an eddy in deep water increased the noise level by 3-5 dB.

Rain Noise

In Sources of Underwater Rain Noise, Hugh C. Pumphrey, Department of Engineering, University of Cambridge, discussed the mechanisms by which rain falling onto a water surface generates underwater noise. He discussed the power spectra with a peak at 14 kHz for a variety of rainfall conditions. The spectra drop sharply to a minimum at about 8 kHz then rise monotonically from there to 1 kHz. At frequencies above the peak frequency, the spectra drop off at a rate of 9-dB/octave. He then related this spectrum to the events shaping it: the peak at 14 kHz being caused by the bubble entrained by each drop, in a certain range of drop sizes, impacting at certain velocities. He hypothesizes that the noise at the lower end of the frequency spectrum is caused by the impact and, more importantly, the bubble resonance of larger drops. He concluded that most of the underwater noise of rain is because of bubble entrainment.

Herman Medwin, Physics Department, Naval Postgraduate School, Monterey, California, in Impact and Bubble Radiation from Obliquely Incident Rain, expanded on these mechanisms by describing the results of his laboratory experiments in which raindrops hit the water's surface at an oblique angle. He found that oblique drops only create bubbles a small percentage of the time. Whereas normal incidence, terminal velocity drops virtually always create bubbles. Further, the frequency from these oblique drops is above the verified 15 kHz for normal incidence drops. Also, oblique drops radiate more impact energy and less bubble energy, and the radiation pattern of obliquely incident drops is not that of a pure dipole.

Jeffery Nystuen, Department of Oceanography, Naval Postgraduate School, built upon Medwin's findings in An Explanation of the Sound Generated by Light Rain in the Presence of Wind. He used the observation of a reduced magnitude, along with the shifting higher and broadening of the high-frequency peak in the noise spectrum with oblique impact of rain, to explain the change in the noise spectrum observed in light rain in the presence of wind. He demonstrated that for wind exceeding 3 m/s, most of the sound generated by light rain is caused by the impact of raindrops rather than the bubbles created.

Interesting New Ideas

Several interesting new ideas in natural physical sources of underwater sound were reported. David Farmer, Institute of Ocean Sciences, Sidney, British Columbia, Canada, turned things around in The Use of Ambient Sound as a Probe of Ocean Surface Processes. He reported that results from new types of instrumentation are yielding measurements of frequency distribution of radiated sound, its temporal variability, and spatial pattern. Using this equipment, his observations tend to support the concept of wave breaking as a primary sound source over a broad frequency range. He foresees a much wider application of this newly available instrumentation. "Two dimensional, time-dependent patterns of sound sources should provide a basis for interpretation of wave-breaking dynamics and its dependence on the directional wave spectrum and other relevant environmental factors."

Peter Thorne, Proudman Oceanography Laboratory, Birkenhead, Merseyside, U.K., in Seabed Saltation Noise, introduced the idea of the ambient sea bed actively producing noise in the 30- to 300-kHz band. "There is the possibility ... that mobile surficial sediments, transported under the influence of currents and wave action can by interparticle collisions behave as an active originator of underwater sound." Experimental evidence (in the laboratory on colliding spheres and irregular-shaped particles, and, at sea, over several tidal cycles over a shingle bed subject to tidal currents enough to transport the material) was consistent with sediment-generated noise being a significant contributor to background level. Also discussed was the inverse case of applying sediment-generated noise to study sediment transport and the advantages of this method over more conventional methods.

Another interesting new idea was advanced by A.V. Furduev, Institute of Oceanology, U.S.S.R. Academy of Sciences, Moscow, in Possible Nature of High-Frequency Ocean Noise in the Absence of Wind (Hypothesis and Estimation). Furduev looked at the situation of dead calm over the ocean without the wind, wave, or turbulent power to which ocean noise is normally ascribed. Even in these conditions, noise in the 1- to 30-kHz range has been recorded. He hypothesizes that the source is cosmic radiation penetrating the sea surface. He provides calculations comparing intensity of surface noise spectral density sources with the surface density power connected with cosmic radiation. This comparison supports his hypothesis.

Inter-Noise 90 International Conference on Noise-Control Engineering

by G. Maidanik and J. Dickey of the David Taylor Research Center. G. Maidanik is a Principal Scientist (with the Ship Acoustic Department) at the Carderock Laboratory in Bethesda, Maryland, and J. Dickey is a Senior Scientist (with the Propulsion and Auxiliary Systems Department) at the Annapolis Laboratory in Annapolis, Maryland.

Introduction

Inter-Noise 90 was held in Göteborg, Sweden, August 13-15. The theme was "science for silence." The technical program was held at the Conference and Exhibition building of Chalmers University of Technology (CUT). This building adjoins the building that houses the renowned Department of Applied Acoustics. The conference facilities readily accommodated the eight parallel sessions and the over 800 noise-control engineers that participated. The lecture halls were adequately appointed and facilitated.

Distinguished Lectures

Three distinguished lectures were presented. Prof. M. Heckl, University of Berlin, delivered the first lecture at the opening plenary session. The title of his lecture coincided with the conference theme. He presented a historical perspective and an overview of noise control. In typical Heckl fashion, it was well organized and clear, with the proper mix of theory, experiment, and rule of thumb. Extrapolating from the present to the future, he made a point to disagree with those colleagues who claim that silence is on hand in principle, and it merely remains to implement silence. On the one hand, silence can be achieved by switching off all sources. On the other, it can be achieved by bringing into play an all-purpose active control. Heckl asserted that between these two purported extreme silencing schemes lies a vast fertile area of science. Raising a corps of enthusiastic young scientists to work in this area is the real challenge to the noise-control engineering community.

As the second distinguished lecture, Prof. A. Flock, Karolinska Institute, Stockholm, presented a fascinating overview of the "Active 'Noise' in the Hearing Organ, an Aid to Auditory Sensitivity." A video showing the action of individual muscle fiber to sound stimuli seemed to evidence that the hearing organ contains an active feedback mechanism that controls auditory sensitivity. He argued that instabilities that may occur in this feedback mechanism may be responsible for tinnitus. Tinnitus is constant sound in the ear such as ringing, hissing, buzzing, or noise like waves crashing[1].

Prof. A. Cummings, University of Hull, England, presented the third distinguished lecture entitled, "Prediction Methods for the Performance of Flow Duct Silencers." He reported that progress in this endeavor has been chiefly achieved in those silencers in which the walls can be approximated by point reacting and "lumped" impedances. Wave-bearing walls resist adequate analytical predictions, especially at the higher-frequency range in which modes exist with a circumferential index that exceeds unity. This is not surprising since it has been contended recently that even in the simpler room acoustics, where flows are considered absent, analytical predictions resist proper accounting when wave-bearing walls are introduced. At the lower-frequency range, Cummings claimed that computational techniques already exist. Some are fast developing, with capabilities of adequately predicting the performance of silencers under most normal conditions. At the higher-frequency range, he believes the problems of prediction will persist. Nonetheless, some of the problems that beset proper analytical predictions at the higher-frequency range are being systematically defined.

Contributed Papers and Technical Categories

Approximately 330 contributed papers were presented in eight parallel sessions. The sessions were roughly organized into the following categories:

- Environmental Noise
- Building Acoustics
- Transportation Noise
- Duct Acoustics
- Noise Control
- Active Noise Control
- General Analysis
- Signal Analysis
- Low-Frequency Noise and Vibration
- Vibration and Structure-Borne Sound

[1] AMA Home Medical Library, Practical Family Health, C Clayton, MD (Medical Editor), published by Readers Digest, 1989.

- Engineering Application of SEA
- Sound Power Measurements

Review of Contributed Papers

Befitting a conference on noise-control engineering, there were more papers under the general category of "Environmental Noise" than any other single category. The usual papers on the generation and propagation of noise, building and airport noise, wheel and rail noise, and road and tire noise were delivered and discussed. There was also a workshop session that concerned the requirement that must be met by, and the labeling of noise from, household appliances and other man-made machines that produce noise that is detrimental to man. There were no official participants in this special session from the U.S. Is that a signal?

There were several papers on the now popular intensity in noise-control engineering and, of course, the ever-promising active control of noise. D.Y. Ma, Institute of Acoustics, Academia Sinica, Peoples Republic of China, presented a paper entitled, "Active Noise Control in Reverberant Rooms," representing active control of reverberant sound fields. Notably, several papers dealt with the active control of aircraft interior noise. Discussions centered on the relative merits of global, zonal and local control. Papers by G.P. Eatwell, NCT Ltd., Cambridge, England, and J.M. Mason and F.J. Fahy, Institute of Sound and Vibration Research (ISVR), Southampton, England, elicited active discussion. The latter presented results validating a reciprocity technique for measuring transfer functions for aircraft engine/cabin noise. Mentioning transfer functions, R.H. Lyon and his student, M. Tohyama, Massachusetts Institute of Technology, Cambridge, presented a fundamental paper showing that features in the transfer function in a reverberant room (e.g., the accumulated phase) are related to the poles and zeros in the sound field.

In addition to the distinguished lecture by Cummings, there were several other good papers on duct acoustics. In particular, there were excellent overviews by P. Munjal, National Institute of Science, Technology, and Development Studies, New Delhi, India, and P.O.A.L. Davies, ISVR, Southampton, England, on mufflers and ducts with flow, respectively. There was another good paper by Y. Gervais and J.L. Peube of the Laboratoire d'Etudes Aerodynamiques, Poitiers, France, which discussed some subtle effects of temperature and flow profile on the acoustic propagation in ducts.

An entire session was devoted to engineering applications of Statistical Energy Analysis (SEA) reflecting the interest that this technique is generating. As usual, some challenged the validity of SEA as such, some demanded better definitions and descriptions for the confidence levels on the results issued by SEA, and several extensions and reformulations of SEA were proposed. A wave approach, rather than the conventional modal approach, to the development of SEA is becoming a topic of interest. K.H. Heron, Royal Aerospace Establishment, Farnborough, England, and (in another session) Y. Lase and L. Jezequel, École Centrale de Lyon, Écully, France, presented papers on the subject. Such a development is central to some of the recent work by this article's authors. The fundamental and broad interest in SEA for engineering applications indicates that it is developing and here to stay.

Final Remarks

To us, and to many other attendees, the conference was enjoyable and useful; it was a good and wholesome inter-noise conference. The next inter-noise conference will be held in Sydney, Australia. From the presentation made by representatives of the Australian organizers, it should be different, but also an enjoyable one.

Copies of the two-volume proceedings in English are available at $120 (postpaid) from: Noise Control Foundation, P.O. Box 2469, Arlington Branch, Poughkeepsie, New York 12603.

Changes at Dutch Research and Development Institute

by David Feit

Introduction

The TNO, the Netherlands Organization for Applied Science of which TPD-Delft is a major part, is preparing to meet the changing economic and political environment in Europe. The present objective of TNO is to serve Dutch society and government agencies in applied scientific work. After 1992, other European research institutes and companies will be able to compete for government projects. On the other hand, there will be more opportunity for TNO to gain additional international contracts.

The Acoustics Division of TPD-Delft, (see ESNIB 90-01:1-2) stands to benefit from such developments. One of the key technical challenges of the 1990s is the environment, and the division's expertise in environmental noise control will allow it to expand its work base, and extend its influence on a worldwide basis. This is especially true about its work in ship acoustics, and the problems of ship noise standards and habitability to which it has contributed so immensely in the past.

Acoustics Division Developments

Many changes occurred in 1989 within the Acoustics Division. The division initiated several large projects requiring a large personnel increase which is now underway. Professor Dr. J.W. Verheij accepted an appointment at Delft University of Technology. Since 1985, he has been an associate professor at Eindhoven University of Technology, and he continues to work at TPD-Delft as a part-time scientist. Dr. Bjorn Petterson, formerly of the Swedish Royal Institute of Technology at Lund, also accepted a position at TPD-Delft.

Workload in the Division

In 1989, about 45 percent of all the projects were related to environmental noise control. In some of the projects, the effectiveness of various noise screens was measured. In one project, the ORE (Office de Recherches et d'Essais of the Union Internationale des Chemins de Fer) has requested that TPD-Delft and three other institutes in the U.S., Federal Republic of Germany (FRG), and France perform a joint investigation of the rolling noise of trains. The latter is a 3-year project and is well integrated with other internal Dutch projects.

Defense research accounts for 35 percent of TPD-Delft's acoustical work. Many of these projects are commissioned by TNO's Defense Research Organization and by the Royal Netherlands Navy. In this area, noise control of ship's radiated noise is the major activity. In the NFR-90 project (NATO Frigate Replacement for the 90s), TPD-Delft played a large role in the propulsion unit selection and the noise control measures.

About 10 percent of the Acoustics Division's work is devoted to transportation noise. An example of some innovative work is a project to control ship's cabin noise using active control. In Europe, the use of the term anti-noise for this application has become in vogue. They are also involved in a project related to national and European regulations related to the acoustical quality of buildings.

Noise and vibration control within the workplace makes up the final 10 percent of the workload. In this area, they are investigating hand and arm vibrations caused by hand-held tools, and the control of wood-cutting tool noise. They also act as noise control consultants on specific problems in factories, workshops, and onboard ships.

Cooperation with the European Community

Under the COMETT program, TPD-Delft, the Institute of Sound and Vibration Research, Southampton, U.K., and Metravib RDS of Lyon, France, have developed the course "Noise Reduction of Machinery Installations by Vibration Isolation." The first version of this course was given in the Netherlands in October 1989, and attracted 50 participants from 12 countries. In the fall of 1990, France will host the next version.

In another European Community (EC) effort, TPD-Delft with the Fraunhoffer Institute fur Bauphysik, Stuttgart, FRG, (see ESNIB 89-08) have agreed on the mutual use and translation of test reports on the acoustical properties of building construction types. Through this agreement, firms that have had their products tested in one country do not have to have them repeated in another country. A standard translation of the report is made and is valid in the other country. As time goes on, such agreements will have to be made by test laboratories in all the EC countries, and I assume in areas other than acoustics as well.

Future Prospects

The years ahead look very good for TPD-Delft, and the Acoustics Division prospects are excellent. Their longstanding work and reputation in environmental acoustics will undoubtedly bring them an expanding workload as the EC becomes further integrated after 1992.

Cherno More or Black Sea '90 Conference

by David Feit

Introduction

Bulgaria, like the other Central European countries that were formerly under Communist domination, is increasingly looking towards the West to help bring it prosperity and personal freedom. During this possibly long period of transition, there are many problems to overcome. The grave shortages of hard currency now needed to pay for its energy supplies and capital investments affect all segments of society, including science and technology. Research institutions are now being forced to find ways of self financing rather than rely on the munificence of the state. More and more, we are seeing the formation of companies where the staff are the shareholders that seek to sell their technological capabilities both inside and outside their own country. Some scientific organizations have recognized that conferences offer them the opportunity to attract hard currency so sorely needed to travel abroad. Upon arriving at the Varna Airport in mid-September, I noticed that besides the Black Sea '90 Conference that I was to attend, there were two other concurrent scientific meetings.

Unfortunately, however, for this conference's organizers, there were few "hard currency participants." During a postconference interview with the organizers, I learned there were 171 official registrants. From the attendance list, I counted only 153 from 12 different countries. Of these, eight were from the West and presumably paid their registration fees in hard currency. The breakdown was: U.S. - 3, U.K. - 2, the Federal Republic of Germany (FRG) - 1, Italy - 1, and Japan - 1. The U.S.S.R. and Bulgaria had the most participants, with the rest from other formerly Eastern Bloc countries. I asked some Polish engineers their reasons for attending this meeting. They said this is a rare opportunity to learn what the Soviets are doing in marine technology.

Dr. Nicolai Dukov, President of the Center of Ocean Engineering, Ltd. (COE), cochaired and organized the meeting. The COE is a private venture company started by staff members originally employed by the Ship Research and Development Institute, Varna, and the Central Laboratory for Automation and Scientific Instrumentation, Bulgarian Academy of Sciences, Sofia. This is another example of the movement away from central planning towards a free market type of economy.

Cochair was Professor V. Yastrebov, Director of the Shirshov Institute of Oceanology, probably the largest oceanographic institute of the U.S.S.R. Academy of Sciences with facilities in Moscow, Leningrad, Kalingrad, and Gelendzhik. In the past two years, the Shirshov Institute has been very actively marketing its capabilities and facilities in the West. The Woods Hole Oceanographic Institute and the Shirhov Institute recently signed a cooperative agreement. Institutes like the Shirshov typically have enough internal funding for the scientific staff, but are trying desperately to get hard currency commitments to keep their research facilities (in this case, several modern and well-equipped research ships) in operation.

At the opening plenary session, Yastrebov was scheduled to make welcoming remarks, but because of "management problems" in Moscow, an associate substituted for him. In another context, I have since received a telex from M. Vinogradov who signed it as Acting Director, Shirshov Institute of Oceanology. Whether the two matters are related is unclear.

Organizational Problems

Some of the organizational aspects of the meeting were well below expectations, especially considering the meeting was controlled by a professional conference organizer. One of many disturbing aspects of the conference was that the Western participants were assigned to hotels that charged in dollars. Our Eastern comrades stayed at a neighboring hotel where the charge was in Lev (Bulgarian currency) making it much more affordable for them, but expensive for us. Rather than charging an all-inclusive fee, Westerners were offered an "a la carte" selection, including a charge per day of attendance, proceedings, local transportation, keynote luncheon with no keynoter, etc. The cocktail party cost $20 per person; food and drinks were gone about 10 minutes after the door opened.

Although the meeting was held in a rather modern-looking and presumably well-equipped Palace of Sports and Culture, there were several technical problems. The sessions had hardly started when the first speaker turned on the overhead projector and it did not work. After three tries, a working projector was found. The second speaker used slides, but the inevitable happened. They had been inserted incorrectly, causing another embarrassingly long delay. Although the official language for the meeting was English, some of the Russian speakers wanted to give their talks in Russian. The translator, a retired chemistry professor from the

University of Sofia, did an excellent job, but he was not always available.

There were 27 technical exhibitors--two from the U.S. One was Klein Associates, Inc., Salem, New Hampshire, who manufacture and sell side-scan sonar devices. The other was Windate Enterprises, Inc., Spring Valley, California, publishers of SubNotes trade journal. In a free market country, conference organizers or promoters normally must guarantee the conference venue a rental fee for each exhibitor space. Because of the small "hard currency" turnout for this conference, the conference may have been financially disappointing to the organizers and promoters.

Conference Highlights

Despite the problems, the organizers declared the conference successful. West Star Productions organized the exhibits. For balance, I append its press release (see page 42). The Sofia Press and official TV provided adequate coverage. As far as I could tell, aside from cable TV in my hotel in Sofia, there is only one TV channel in Bulgaria.

The Bulgarians expressed surprise at the many Soviet scientists who attended. In fact, during this interview I was told of some unusual development that took place during the conference. According to Dukov, a group representing the Central Research Institute of Structural Materials, "PROMETEY", Leningrad, U.S.S.R., headed by Dr. Juli Hessin, came to the meeting with a proposal to COE. They wanted to form a joint venture company to sell to the West specialized structural materials suitable for deep-submergence technology. The principal product to be marketed would be deep-submergence pressure spheres or cylinders made of titanium and high-strength steels. In their nonmetallic line, they claim to be able to produce high-strength spheroplastics for pressure vessels of manned and unmanned submersibles capable of depths up to 6,000 m. The Soviet institute also claims to produce 2 1/2 times the output of any other plant of its type. The COE will be the middleman in the contracts with the West, and will provide the finished products using Bulgarian factories.

Another Soviet enterprise that featured in this meeting was the arrival of the Soviet research vessel *Gelendzhik* in the Varna port. This ship, newly built and commissioned in February 1990, is operated by Yuzhmorgeologiya, the U.S.S.R. Ministry of Geology. The Western participants, three Poles and two Bulgarians, visited the ship at the port. One of the tour members was Harald Backer of GEOMAR Technology, FRG. He was familiar with the ship since he designed some of the advanced handling and coring equipment on the ship. The ship's chief scientist conducted the tour, assisted by a staff member who translated. The ship is 105-m. long, with a beam of 16 m., and a displacement of 5600 metric tons. There were nearly 100 people aboard; approximately half are operating crew and half are research personnel. We saw their most recent unmanned submersible equipment. These are used in geological surveys of the bottom, echo sounding, exploring and prospecting for mineral resources, and environmental monitoring. The accompanying photograph shows the stern launching of a deep-diving submersible that photographs the seabed. A unique feature of this submersible is the actively controlled lifting surface that maintains the camera platform at a constant depth over the sea floor. The rubber protrusions seen in the photograph protect the lifting surface during launch and recovery, allowing operation in relatively high sea states. Obviously, this vessel is available for any cooperative research program at a very reasonable price.

Technical Presentations

There were a few very excellent and informative presentations, mostly from the Western presenters. Unfortunately, many of the other presentations were not up to the standards that I have observed at most meetings in the West. Probably, this is the lack of experience in giving technical presentations in English. There were some presentations, however, that even after translation seemed to be nothing more than an advertisement for various technical products.

For most of the week there were no parallel sessions; even then, I never counted more than 30 members in the audience. At one session, there were six papers to be given; two were not given. The audience was me and five others.

This meeting had a more technological flavor rather than scientific. Of the papers I heard, only one impressed me as being of scientific rather than technologic value. This was a paper on the "Effect of Dispersion in Bubble Media on Parametric Acoustic Array Formation in the Ocean Subsurface Layers" by V.A. Bulanov and V.D. Polonichko, Institute of Marine Technology Problems, Vladivostok, U.S.S.R. The authors show how the efficiency of parametric sources depends on bubble concentration values and the bubble size distribution function. They conclude that in subsurface layers with a sufficiently high concentration of bubbles, one must incline the radiation axis of the array relative to the layering direction. In a response to a question from a Polish participant about the frequency range considered, the presenter stated that they are using pumping frequencies in the range of 150 kHz to produce 15-Hz directional beams. I mention the nationality of the questioner because throughout the meeting, the Polish participants asked the Soviets the most sensitive questions. The answers usually were surprisingly quite candid and unambiguous. The major session topics were:

- Underwater manned vehicles and ROV's
- Hydroacoustic methods and systems
- Subsea system design
- Data acquisition and processing
- Deepwater advances.

In reading the proceedings, I find some of the papers completely unintelligible even when I am somewhat familiar with the subject area. Apparently, some of the papers have been machine translated with no human input. Rather than review or comment on specific papers, which for the most part are outside my area of expertise, I have made only some general remarks.

Concluding Remarks

The Soviet technology and experience in deep diving submersibles appears very impressive. Over the past two decades, they have built and tested at least 20 vehicles. Many are probably used for deep sea exploration and survey. Others may have been built for military applications such as rescue vehicles.

Appendix

BLACK SEA'90 RATED A FIRST-TIME SUCCESS; BLACK SEA '92 ON
(Press Release from West Star Productions, Spring Valley, California)

(Varna, Bulgaria) Black Sea '90, the international ocean and marine exhibition and technical conference that was held September 17-21, 1990 in Varna, Bulgaria, was declared a success by the show's organizers. The exhibition covering 54 stands attracted over 500 visitors and nearly 200 delegates representing 12 countries registered for the technical conference.

"I am extremely pleased that our first attempt at organizing an East-West trade show and technical conference of this magnitudewent so smoothly," said Chairman, Dr. Nikola Dukov, President of the Center of Ocean Engineering (COE), the show's main sponsor and organizer, "While the majority of attendees were from East European countries and the Soviet Union, those from Germany, Italy, UK, Japan and the United States were pleased with the excellent technical interchange, the many contacts made and the strong possibilities for new business."

Deam Given, West Star Production, Black Sea '90 Exhibition Manger, echoed Dr,. Dukov's summary and added, "For a first-time event occurring during the tumultuous changes on-going in Eastern Europe and the USSR, I think we did quite well. New ocean and underwater products and technology were unveiled and there was a lively exchange of information throughout the show. The exhibition was superbly constructed and decorated and my hat's off to COE employee, Milan Assadourov, who was responsible for that.

The show's overall accomplishment will be a strong base in attracting more people and companies--especially from the West--for Black Sea '92,"

A total of 71 technical papers were presented to delegates. English was the official language of the conference, although translation services were available to assist a few speakers. These paper, written in English, are available in a bound set of Black Sea '90 proceedings. These may be ordered through West Star Productions at US $75.00@ + air mail p&h($5.00 USA & Canada/$14.00 overseas).

A social program was also an important aspect of Black Sea '90. Delegates were treated to an excellent selection of splendid Bulgarian wines, champagnes and brandies during a reception in the exhibit hall. The organizers also sponsored an official dinner at the Monastirska Izbz, a traditional Bulgarian eatery located at the nearby Drouzhba resort. In addition, many individuals opted for sight-seeing tours of the area, enjoyed the warm water of the Black Sea or were content to visit the many museums and other tourist attractions of Varna.

Black Sea '92 is tentatively scheduled for September 1992 in the Culture & Sports Center, Varna Bulgaria. More information will be provided when the dates become firm.

Acoustics Research at Soviet Institutes

by David Feit

Introduction

Glasnost of the past few years and the ending of the Cold War during the last year provided me the unique opportunity to visit previously closed, somewhat secretive institutes in the Soviet Union. I will report here on the Shirshov Institute of Oceanology (Shirshov) and the Andreev Institute of Acoustics (Andreev), both in Moscow, and the Krylov Shipbuilding Research Center (Krylov) in Leningrad. In spring 1990, I met Dr. Nahum Veksler at the British Institute of Acoustics conference in Southampton, England. Then I learned about the EUROMECH 271 conference on Diffraction of Waves by Obstacles and Inhomogeneities in Fluids to be held in Kiev, the Ukraine, in October 1990. I planned to attend this meeting. At the same time, I began to ask scientists at these three institutes, whose work I was familiar with, about visiting their laboratories. Last-minute difficulties in obtaining my visa to visit Kiev prevented me from attending the EUROMECH conference. However, I visited the other institutes. Prof. D. Crighton, EUROMECH Committee president and conference cochair also did not receive his visa in time. These difficulties may have been fortunate since I later learned from newspaper reports that there were political riots in Kiev the day the meeting began.

Shirshov Institute of Oceanology

My first day in Moscow was spent sightseeing and learning how to use the Moscow underground. This, by the way, is just about the only consumer-oriented technology that made a favorable impression on me.

Armed with this experience, I was ready to embark upon my first liaison visit to the Shirshov where I met with Dr. Boris Kuryanov, head of the Laboratory of Ambient Noise. This laboratory is one of three at the Shirshov dedicated to various aspects of acoustics research. The Shirshov is housed in a large, grey nondescript office building in the southwest part of the city, about a mile from the Soviet Academy of Sciences (Academy). The Academy provides the Shirshov with its funding and thereby controls the work going on there. I understand that the institutes have been recently directed to become more self sufficient, and to seek funds from outside sources, including countries outside the Eastern Bloc.

Like many other Academy buildings, this building is not well maintained. The large, reinforced concrete structure stands out only because of its height. As we pulled into the mud-strewn parking lot, I noticed several apparently abandoned automobiles lining the driveways. I was told that they were not abandoned, but merely awaiting repairs or spare parts that are difficult to obtain. Among the Ladas, Skodas, and Trabants, one finds an occasional old Volkswagen or Volvo brought back by the fortunate few scientists who traveled to the West and somehow managed to take along enough hard currency to make the purchase.

As I entered the building, I immediately pulled out my passport and identification preparing myself for the usual barrage of paperwork necessary to enter such an institute elsewhere in Europe. I was quite surprised when a woman waived me through the main door. She did not asked my name and did not seem to care about who I was, where I was from, or why I was there. The hallways are very dimly lighted. The few support staff members I came across appeared very lackadaisical.

Although Dr. Kuryanov heads a group of about 20 scientists, he has an office that is probably no larger than 80 square feet in area. During our discussions, there were three of us in the room with hardly any room to spare. At one point, another scientist, Dr. V. Zhitkovski, chief of the Laboratory for Scattering and Reflection, entered the room. Because of the small quarters, I met with him individually.

The Shirshov Institute Research Vessels

Dr. Kuryanov is heading a scientific expedition that will take place during spring 1991. He is very eager to have some U.S. participation on this cruise, and I believe it would be at no cost to the visiting party aside from room and board. My impression is that they would be looking at this initial cooperative activity as a loss leader. The scientific team will use the Shirsov's newly acquired vessels. The R/V Academic Sergei Vavilov, a general purpose research vessel, and the R/V Academic Ioffe were built for the Shirshov by Hollming Ltd. of Finland and delivered in 1988-1989. In my discussions with Kuryanov, it was clear that they are looking to the West for cooperative scientific experiments that would use these research vessels in the future and help pay for their operating costs.

The ships have nearly 20 laboratories equipped according to specialized research tasks; e.g., meteorological, hydrological-hydrochemical, echo-sounding. In addition to these laboratories, three changeable containerized laboratories can be brought aboard to conduct specialized tasks requiring unusual equipment.

For acoustic propagation studies, they use the Ioffe as the source ship and the Vavilov as the receiving vessel. For example, the Ioffe is equipped with a high-power, deep-sea sound source, a parametric echo sounder working with 20-30 kHz sources to produce directive beams at 3-5 kHz. The vessel also has an acoustic doppler current profiler working at 150 kHz and capable of measurements down to 300-m depth or at 75 kHz profiling down to 700-m depth. They are using acoustic holography to do bathymetric surveys of the bottom. For this task, they have constructed a planar array made up of 256 hydrophones (16 x 16m) covering an area of nine square meters (3 x 3m). They have bought some electrodynamic sources operating in the frequency range 50 to 500 Hz and used in a linear source array. Each ship can accommodate up to 128 people and can conduct expeditions requiring a cruising range of 20,000 nautical miles without replenishment of food and fuel.

Ambient Noise Research at the Shirshov

Kuryanov's research interests are in low-frequency ocean ambient noise. In the past, they have used a small three-person submersible with an 80-m antenna connected. Measuring ambient noise requires sensing very low-level signals over a wide frequency range. Because of the submersible's own ship-radiated noise, the manned submersible mounted system was not very useful for their purposes. They have now changed to a system using an automatic bottom station (ABS) that can be planted in depths up to 6000 m and can record data on 14 channels over a 72-hour period. The ABS can stay submerged for up to one month at a time.

The station is equipped with a data communication system allowing for data transmission out to a 15-km range. The arrays are equipped to hold up to 16 hydrophones with variable spacing between phones. In addition to measurements of ambient noise, Kuryanov and his group are using data recorded on their system to estimate bottom characteristics. This is achieved by measuring the time correlation between direct paths and bottom-reflected paths to the beam-forming array of the ABS. Kuryanov and his assistants, Drs. Vidinov and Moiseyev, gave me some copies of papers that they prepared about the subject.

Another recent project that we discussed was a study of the structure of internal waves using two of the ABS-mounted arrays--one for transmission and the other for reception. They are looking at the propagation of ambient noise using theoretical models that use ray acoustics and the exact wave approach for lower frequencies. As has been reported by many others, their computational resources are very meager. Moiseyev sat in on the discussions and interpreted for Kuryanov who had some difficulties with spoken English. (Moiseyev said he had learned English by listening to the Voice of America and BBC broadcasts.) He presented a simple theoretical explanation for the existence of a beam maximum at an ocean front using a simplified adiabatic approach. Moiseyev is interested in visiting the U.S., so I explained the Office of Naval Research European Office (ONREUR) Visiting Scientist Program.

Acoustic Scattering and Reflection Research at the Shirshov

My next visit was with Dr. Zhitkovskii who is the chief of the Laboratory for Scattering and Reflection. He has been a researcher since 1957 and was formerly affiliated with the Andreev. Both he and Kuryanov came to the Shirshov about 15 years ago to be laboratory heads. Apparently about that time, the Andreev was disassociated from the Academy and directed by the Ministry of Shipbuilding. Although not explicitly stated, I think the Andreev might have been more involved with defense applications. Zhitkovskii's group includes about eight scientists, six engineers, and several technicians and support staff.

Zhitkhovskii's work involves studying the geomorphological characteristics of the deep ocean bottom using acoustics as the probe. He stated that modeling of the bottom as a rough scatterer is a good approximation. He claims to have been an early proponent (first mention in 1962) of using acoustical means to identify manganese nodules (MN) at the deep ocean depths. Areas of the bottom covered by MN are small (about several hundred meters wide). In such areas, the reflection coefficient does not depend upon angle and is 10 to 15 dB higher than areas not covered by MN.

More recently, he has turned his attention to more shallow oceans where the bottoms are less rough but covered with an absorbing bottom surface layer, and the sound scattering is dominated local inhomogeneities within the bottom itself. Shallow waters, by his definition, are of the order of 100-m deep. Just recently (in fact, over only the last year or so), his group has been directed to look at the hydroacoustic detection and classification of icebergs.

Dr. V. Mosgovoi, who sat in on this discussion, then described the work that he is pursuing. He is looking at sound scattering from biologically inhabited layers; i.e., horizontal aggregations of biological specimens. He probes these layers with echosounders in the frequency range from 2 to 50 kHz lowered from the surface. Also, he is interested in sea surface reflection and refraction, especially where layers of bubbles and marine animals exist. They have not observed any anomalies related to grazing incidence sound at the sea surface.

Dr. Veronovich directs the Shirshov Acoustic Propagation Effects Laboratory but he was not available. This group was formerly headed by Academician L.M. Brekhovskikh, who now directs the U.S.S.R. Ocean Acoustics program from the Academy.

I came away with the feeling that the Shirshov is doing first-rate work in ocean acoustics with excellent measurement facilities available to them. As expected, large-scale computational efforts are not of interest here because of computer resource limitations. Both of the laboratory chiefs I interviewed came to the Shirshov from the Andreev where they spent many years gaining experience. The people I talked to were very open about their work. Although acoustics is considered to be a sensitive area because of its potential military applications, there were no signs that this institute is involved in or interested in pursuing such work. The rather perfunctory (or nonexistent) security precautions at the main entry point are further testament.

The Andreev Institute of Technology

The prevailing atmosphere at the Andreev is quite different. An escort in a chauffeur-driven car took me to the Andreev. One must pass through a rather formidable gate controlled from a guardhouse. Walking through the halls, I found the physical appearance and conditions to be much better than at the Shirshov, but in a very somber way. The offices that I visited were spacious and well appointed with the ever-present portrait of Lenin. Within walking distance of the buildings is a large apartment block for members of the Andreev. I could not get a close look, but given the rather desperate housing shortages we hear about, this must be quite an attractive incentive to the staff.

My contact here was Prof. Nicolai Dubrovsky who I first met at the conference on Natural Sources of Underwater Noise in the Ocean at the University of Cambridge in July 1990 (see "Natural Sources of Underwater Noise in the Ocean," page 32). Last year, Dubrovsky was elected director of the Andreev.

At the beginning of my visit, Dubrovsky gave me a brief history of the Andreev. This institute is named after Nicolai Andreev, born in 1880 and who is considered to be the father of Soviet acoustics. He established the first laboratory dedicated to acoustics. In 1931, he organized the first Soviet conference on acoustics. He died in 1971, and 10 years ago the institute was named after him on the 100th anniversary of his birth.

Dubrovsky speaks good English; he spent a year at the University of Wisconsin in the early sixties. His scientific interests are in biological, physiological, and psychological acoustics. He has studied and written a book on the acoustical echolocation abilities of dolphins. In addition, he has developed computer models of the auditory systems, and demonstrated the existence of two separate perception models for ambient signals versus echo signals.

Dubrovsky explained the various branches of acoustics that researchers deal with here. For example, they are active in ocean acoustics and hydroacoustics studying problems of propagation, reflection, and scattering from inhomogeneities and irregularities in the oceans, both natural and man made.

To assist in these studies, they can use several research vessels. Their ships generally operate in the central Atlantic and the North Sea. He named four of the vessels; it is unclear whether ships are completely independent of the ones run by the Shirshov (some names were the same). They mentioned two newer vessels--Andreev and Konstantinov. One radiates sound; the other receives sound. This was also characteristic of the two older vessels--Vavilov and Lebedev. The older ships have been in service for about 30 years and will be retired soon.

I told him that I had written to Prof. L. M. Lyamshev earlier in the year. Lyamshev, a Soviet acoustician to whom I had been introduced at another meeting and is well known to Western acousticians, had not yet responded. Dubrovsky promised to check into it and said I could come to the Andreev when I was in Moscow, although he did not volunteer to be an official host. In the Soviet system when someone acts as a host, it obligates him and his institute to get involved with the state bureaucracy in arranging for hotels and travel plans. This is a time-consuming task and better left to others. Since I had already been invited by the Shirshov, their representative took on this responsibility. However, Dubrovsky was very helpful in assisting Kuryanov, my host from the Shirshov, by arranging for train tickets from Moscow to Leningrad by sleeper train.

During my Andreev visit, Lyamshev apologized for not responding. He said he did not receive the letter until after my first meeting with Dubrovsky which occurred about 6 weeks after my mailing. In most circumstances, this would be hard to believe. Now that I have witnessed the situation in the Soviet Union in terms of communication with the outside world, it is much more plausible.

I was taken into Lyamshev's office and he presented me with copies of two of his papers (both in Russian). Much of his early work was in structural acoustics where he made many fundamental contributions. One contribution is a rather definitive work on the scattering of sound by an elastic cylindrical shell. The other is a reciprocity theorem relating the velocity induced on an elastic structure caused by an incoming planewave to the pressure radiated to the far field by a force applied to the structure. Recently, he has been concerned with radiation acoustics, which looks at the acoustical effects caused by the interaction of high-energy radiation with solid or liquid matter.

He said that some of his younger colleagues were that day participating in a group effort by young people to help bring in part of the record-breaking potato harvest that was beginning to rot in the fields. Food production is not a problem; it is transportation and distribution. Those two functions may be politically motivated.

There is a group that works in theoretical modeling. V.U. Zavadskii works in numerical modeling of wave propagation in the oceans using the finite difference approach. Prof. Zavadskii spoke very enthusiastically about his work. He showed me the graphical results of modeling transmission loss in a variable sound-speed channel for variolous profiles. He also has extended his methodology to range-dependent cases. These procedures are programmed and run on small personal computers (PC). I asked whether the Soviet Navy might be in the market for such programs. I think he answered that they would need to develop better small PCs. As I left his office, he gave me a copy of a Russian book that he wrote. I have translated the title as Network (or perhaps Different) Methods in Wave Propagation; it was released in 1986.

Another scientist talked about the reflecting sound from the ocean bottoms and using this information to determine the bottom parameters. When I mentioned that I had heard of similar programs being pursued at the Shirshov, he said they have close contacts with Shirshov. However, I left with the impression that in these very difficult times of reduced expenditures related to ocean exploration, competition has been developing among the institutes. This scientist also a mentioned a square 4 x 4-m array with 256 hydrophones that operates in the 3 to 20-kHz range.

H.M. Avilova showed me the results of an experimental study she has been performing on sound transmission through three different types of shells. For her studies, the sources were placed both inside and outside the shells, and the walls were of multilayer construction. Avilova is a student of Prof. S. A. Rybak and I also talked with him. Like Lyamshev, Rybak is one a senior scientists who has worked in a variety of fields. He and a young scientist recently wrote a review article on low-frequency scattering of sound by cylindrical shells (Muzychenko, 1988). This work is closely related to many ongoing U.S. efforts. I recommend that you study their work if you are interested in the topic.

I should mention that Dubrovsky has named Muzychenko as academic secretary of Andreev. This position is rather powerful in the sense that I believe he has significant input into the technical part of the programs, while the director is in charge of finance and administration.

I was briefed on two other efforts related to machinery vibration control. In one project, Dr. V.B. Stepanov addresses the problems of enhancing vibration damping effects using unusual geometrical configurations of damping treatments applied to plate-like structures. In one study (Stepanov, 1984), he has looked at wave-thick coating applied between the stiffeners of a beam. The damping of the beam is significantly increased by attaching the ends of the damping to the stiffener because of the increased strains induced in the coating. I was impressed by the very fundamental approach to damping treatment theory--an approach not seen often in the U.S. More recently, he has been developing a statistical (thermodynamical) approach to describe the vibrations of complex structures. This is similar to the idea of powerflow analysis of complex structures that has been described and discussed in recent years in Western acoustics literature.

The last project, directed by Dr. G. Lubachevski, that was described to me was related to using active control in machinery vibration isolation. They have applied their approach to a 50-kW power generator that sits on a 2-m long and 1.5-m wide platform. They have successfully reduced the vibration levels transmitted to the supporting structure by at least 20 dB at the single frequency tones of 25 Hz, 50 Hz, and 75 Hz. They emphasized that these were real reductions on operating machinery.

During the course of this rather exhausting day, I was also briefed on the Andreev's work in medical ultrasound. L. R. Gavilov directs a group that is looking at the biological effects of ultrasound. The group is developing ultrasonic tests to diagnose neurological diseases. Another group has successfully developed several surgical tools using ultrasonic cutting. Some of these tools have been introduced clinically. One device that they are particularly proud of is an ultrasonic cutting and separating tool used in treating premature infantile lung disorders.

Armed with the train reservations that Prof. Dubrovsky so graciously arranged for me, I set off for Leningrad to visit the Krylov Shipbuilding Research Center. I was in a two-person sleeping cabin on the "Red Express" that departs Moscow at 11:59 p.m. and arrives in Leningrad the following morning about 8:30. I was curious about the 11:59 p.m. departure. I was told that there is much official travel between the two cities and this departure time gave travelers allowances for an extra day.

The Krylov Shipbuilding Research Institute

I arrived in Leningrad on schedule and were greeted by Prof. V.T. Liapounov, deputy director of the Krylov. T. A. Bachernikhina, deputy head of the Foreign Relations Department, accompanied him and acted as our translator. After checking into Hotel Propulskaya, which is a large western-style hotel located in the southwestern part of the city, I was driven to the Krylov for the first of 2 days' meetings.

The Krylov is located on a large site just outside the city limits. The location is near where the Germans maintained their front lines during the World War II siege of Leningrad. Again, to enter the grounds, I passed through again a security-controlled gate to the main building that houses the director and deputies' offices. Here I met Valentin M. Pashin, the Krylov Director, along with the principal Acoustics Department staff members. The Krylov buildings, like the Andreev, appear to be much better maintained than those of the Shirshov. There is also much new construction taking place on the Krylov grounds.

Marketing of the Krylov

After being welcomed by Director Pashin, I saw a very informative, interesting, and extremely well-produced video that presented an overview of the Krylov and its major facilities. I had already seen parts of the video at the 3rd International Congress on Acoustic Intensity in Senlis, France, in late August 1990. This video is an important part of their marketing strategy to the Western world. From my conversations during this visit, I noted a very strong desire to sell their products and expertise abroad. Liapounov told me that they now have direct authority to negotiate with foreign customers without seeking approval from higher authorities.

The Krylov is the U.S.S.R.'s oldest shipbuilding research center. Built in 1893, it was established in the current city center on the basis of a the original model basin designed under the direction of Admiral Alexander Krylov. The facility has outgrown its original site, has undergone two modernization, and now boasts seven different test basins used for a various purposes. The purposes are:

- Deep- and shallow-water towing tanks
- High-speed towing tank
- Seakeeping, maneuverability, and circulation test basins
- Ice model basin
- Cavitation basin
- Wind and cavitation tunnels
- Anechoic flow facility.

In addition, there are other unique facilities including a variable pressure tank for underwater acoustic testing, pulsators to study fatigue strength, a large deep-submersible testing facility operating up to 3.5 mega-Pascal, and others. Although I have no details, I learned about a deep-sea facility at Sevastopol where they can test large, buoyantly propelled models.

The Krylov employs some 5,000 people. Sixty staff members are considered to be at the highest academic level, with 500 that are qualified engineers and scientists. Of the 700 people in the Acoustics Department, 10 are at the highest level, and about 60 are at the masters degree level.

I presented an overview of the ONREUR and its mission in Europe. I was also questioned about the David Taylor Research Center, Bethesda, Maryland, to which I have now returned. When I discussed the role of the Office of Naval Research in furthering education of scientists interested in fields related to naval applications, the Krylov's deputy director for Education asked how we in the U.S. are succeeding in recruiting young people for scientific and engineering careers. He said they are very concerned about the lack of interest in higher education or career orientation among their young people. I had already gathered this from casual conversations I had with some of my other hosts.

Acoustics Facilities at the Krylov

After these discussions, I was taken on a whirlwind tour of the acoustic and vibration testing facilities. First, I saw the variable pressure hydroacoustic measurement facility. This cylindrical tank (25-m long and 4-m diameter) is used to study the acoustic characteristic of materials, marine equipment, and calibration of hydroacoustic apparatus. The tank is equipped with a turning arm that can rotate objects remotely. The hydrostatic pressure range is 0 to 3 mega-Pascal.

In the next-door test chamber, they have seven different pulse tubes capable of testing samples from 50- to 150-mm diameter with hydrostatic pressures ranging up to 100 MPa at variable temperatures from 1 to 60° C. They claim to be willing to develop prototypes of sound absorbers and acoustic insulation to meet customer specifications.

From there, we moved on to their variable pressure cavitation tunnel where they demonstrated tip and vortex cavitation from a propeller while measuring the acoustic signals being emitted. The chief scientist, Dr. B.P. Grigorjev, expressed concern about the effects of man-made noise on marine life. He asked if we in the U.S. have similar concerns. Then they showed me some of the propellers they had recently been testing in this facility.

I saw two that each had seven-bladed, highly skewed propellers. One had a continuous circumferential attached at about 80 to 90 percent of the radius. They claimed that this was introduced for strength purposes, but had the added benefit of providing damping to propeller vibrations.

Next, I saw their anechoic flow facility where they do measurements related to turbulence-generated noise about appendages and bow domes. V. Sviadosch made the presentation. He authored a paper to have been presented at the 1990 American Society of Mechanical Engineers annual meeting. Unfortunately, he cannot attend the meeting because of financial constraints. In this same area, they discussed an active noise compensation system that reduces the noise of a propeller reaching the bow-mounted sonar of a surface ship.

There also is a specialized facility to examine vibration problems associated within heat exchange equipment. They are offering to provide a calculation procedure for the vibration parameters of multispaced tube bunches in heat exchangers, and to develop methods of detuning the acoustic resonance phenomena in ducts with tube bunches.

Their machinery vibration testing facilities include apparatus to test the vibration transmissibility characteristics of various machinery mounts. One unique test facility, that I had not seen elsewhere, tested mount effectiveness on a moving platform simulating rigid body ship motion. In this same laboratory, they had ready for testing what looked like fairly large-scale simulations of submarine machinery platforms. At one end of the room, they displayed a set of full-scale isolation mounts. They seem to be concerned with deteriorating performance of mounts with time.

After seeing the acoustic facilities, we returned to Liapounov's office for a summary discussion. They were primarily interested in hearing my reaction to their facilities. I had the impression that they were interested in whether or not there would be potential for U.S. purchase of their expertise, equipment, or facilities.

Concluding Remarks

This trip to the Soviet Union re-enforced what I had heard before. The country desperately needs hard currency and this has seriously affected their scientific research institutes. Individual directors seem to have direct authority to hold discussions with foreigners, with the ultimate aim of providing their expertise in exchange for hard currency. Some of their expensive research facilities, such as the research vessels, may have to remain idle and wait for new research expeditions. Individual scientists are worried that the outlook is not hopeful for experimental projects involving large outlays of cash for equipment and personnel.

There seems to be a sense of competition among research institutes. I learned from Liapounov that a new professional society of acousticians has been organized. I noted some friction regarding publication of scientific articles between the Krylov group and the Andreev group. The new society, currently chaired by Liapounov, met in Leningrad the week before my visit. Next year they will begin publishing a new journal that will address more applied work than is currently found in Soviet Physics Acoustics. Prof. A.K. Nikiforiv, head of the Vibration Laboratory at Krylov, will be the editor in chief.

In the end, however, one must realize that the Soviets have invested heavily in acoustics research and they will not easily allow this capability to diminish. The numbers of people currently employed in acoustics research at these three institutes is relatively large, and they are very interested in maintaining these numbers. Although I did not see anything radically new or different in their work, I noted a greater degree of coupling between their research efforts and the practical applications.

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Postscript

The logistical problems of obtaining visas and traveling through the Soviet Union are already well documented in the article by M. Di Capua (see ESNIB 90-08:52-56). I can now attest to the difficult conditions reported there, and recommend to all readers preparing to travel to the Soviet Union that they read the article before embarking. This will help prepare them for the vast differences in living and creature comforts to be encountered during travels in the U.S.S.R.

At the time of my visit, the country was and is still, according to news reports, in a state of economic chaos. There are virtually no goods in the government shops and markets. People not traveling with an officially sponsored tour group will find that current economic conditions in the Soviet Union make it almost impossible to use Soviet currency to obtain even the most basic goods and services. At the same time, unless you are in a hard-currency establishment such as the major tourist hotels or beryoshkall shops, you are warned that using hard currency is illegal, and you can be charged with a felony.

During my Moscow visit, as a guest of the Shirshov, I stayed at at the Hotel of the Academy of Sciences in October Square. One evening, my hosts left me on my own so I decided to eat at the hotel restaurant. That is easier said than done. I was refused admission to the restaurant by an unruly doorman, even though I could see that it had many empty tables. I later learned from my hosts that the only way to get into such a restaurant is to bribe the doorman. It is impossible to hire a taxicab at the official rates quoted in Rubles. If, however, you hold up a pack of Marlboro cigarettes or a ten dollar bill you will be approached not only by taxis, but private cars as well. A pack of Marlboros can be bought on the street for about 25 Rubles which represents about 1/12 of the average monthly salary for a scientist. As I am writing this article in early December 1990, we learn that food has been rationed in Leningrad for the first time since the siege by the Germans in World War II.

Acoustics Research in Italy

by David Feit and LCDR Larry Jendro USN

University of Rome

Professor Zirilli, Mathematics Department, at the "La Sapienza" campus, University of Rome, is doing some theoretical work on inverse scattering as applied to acoustics. He is under contract with the European Office of Aerospace Research and Development. This is work is very fundamental and is also being pursued in the U.S. and elsewhere with some slight variations. The more realistic problem of an elastic scatterer is much more complex, and at present very far from solution.

In inverse scattering, one assumes that an object is ensonified by a known acoustical field, such as a plane wave, and then measurements of the scattered field are made at some distance from the scatterer. Using the scattered field information, one attempts to reconstruct the scattering object that gave rise to the scattered field. He has formulated the problem for the case where the surface of the scattering body is soft scatterer; i.e., the total pressure on the surface of the scatterer vanishes.

At another University of Rome campus, located near the Forum, I contacted Professor A. Sestieri, who is on the faculty of Aerospace and Mechanical Engineering. Sestieri is involved with practical problems of vibrations and acoustics. For example, he is involved in a project with FIAT, the automobile manufacturer, in which he is looking at changes in noise emission caused by structural modification. This project is part of a government-sponsored effort called "Transportation Finalized Programs" in which there is a strong interaction between industry, academia, and research institutions. The impression I got was that such programs have in recent years provided large influxes of money into universities and research institutions, providing some investigators more money than they can reasonably spend.

O.M. Corbino Institute of Acoustics

During my visit to the O.M. Corbino Institute of Acoustics (Institute) of the Italian National Research Council (CNR), I also heard from Professor A. Allipi, the current director, about the "finalized project" connected with transportation system noise. The Institute has been connected with this project for the last 10 years, but my impression is that this source of funding has or will end soon.

The Institute celebrated its 50th anniversary in 1987. Its first director was Orso Mario Corbino, a renowned physicist who was a founder of the Rome School of Nuclear Physics. The Institute's early work was in the area we would now refer to as high-fidelity sound reproduction.

After Corbino's death, and because of World War II's effect on research priorities, attention turned to ultrasonics, and in 1949, the Institute was renamed the National Institute of Ultracoustics. In 1968, the structure was again changed and enlarged when it was renamed the O.M. Corbino Institute of Acoustics. In the intervening years, the work was solely devoted to sound propagation in solids and liquids.

After 1968, the Institute's work broadened and now includes other areas. The areas are environmental acoustics and psychoacoustics, physical acoustics, nonlinear effects in acoustic propagation, acousto-optical interaction, signal processing of acoustic signals, electroacoustic and ultrasonic transducers, and geoacoustics.

The Institute now has a 40-member staff, half of whom are scientists. I understand that they are having some difficulties maintaining staff. In recent years, several senior staff members have been drawn away to the universities. With Italy's prospering economy, scientists and engineers are in short supply and industry is offering large salaries to attract them. Given the rather small staff and the large range of project types, the staff is probably spread rather thin.

During the conversation, I had the feeling that Allippi is concerned about the staffing situation and is probably looking at ways to narrow the scope of the ongoing efforts, while at the same time trying to attract young scientists. Next year, the Institute will move closer to the university.

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